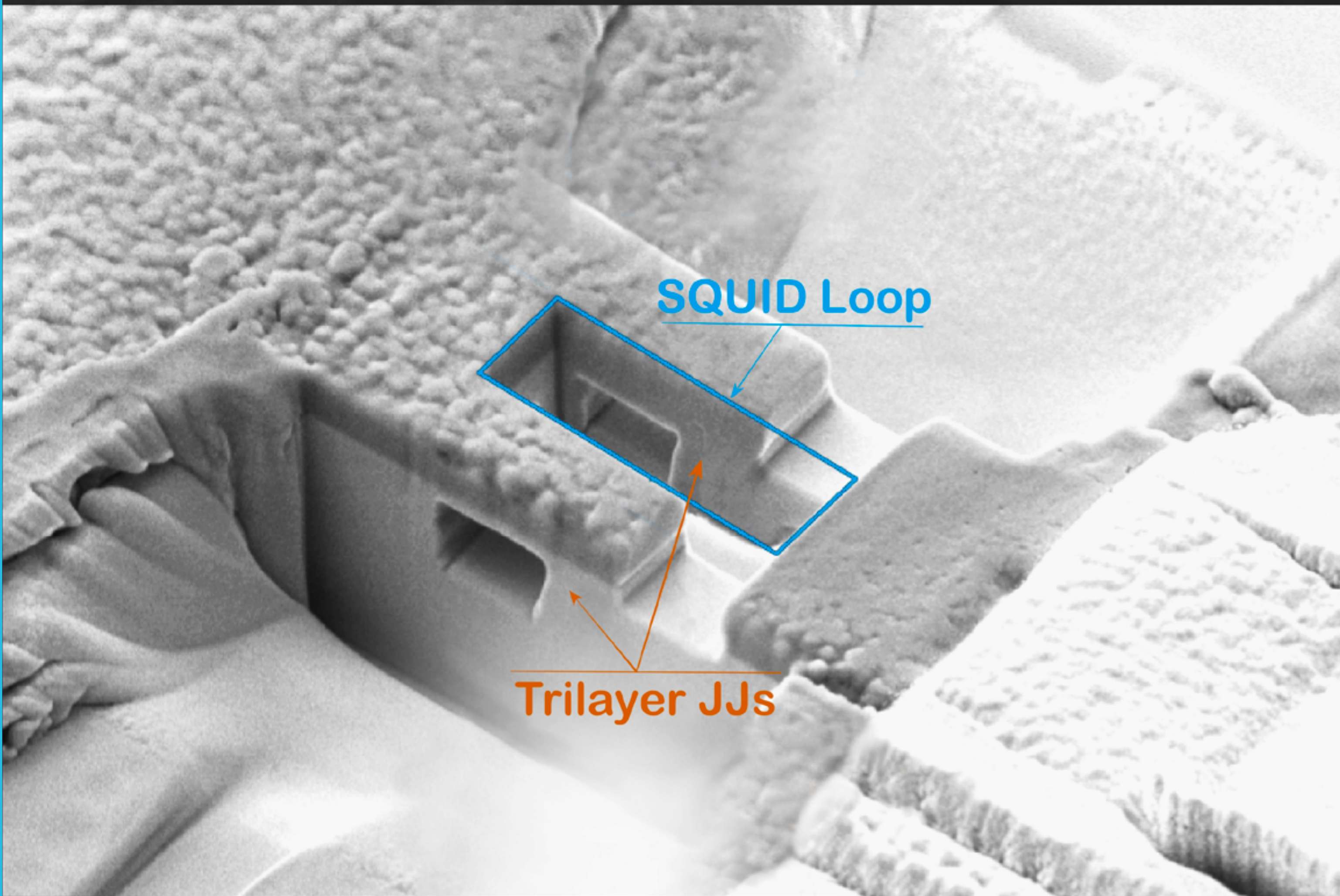
SUPERCONDUCTOR WEEK



Ambature Develops Trilayer HTS Devices

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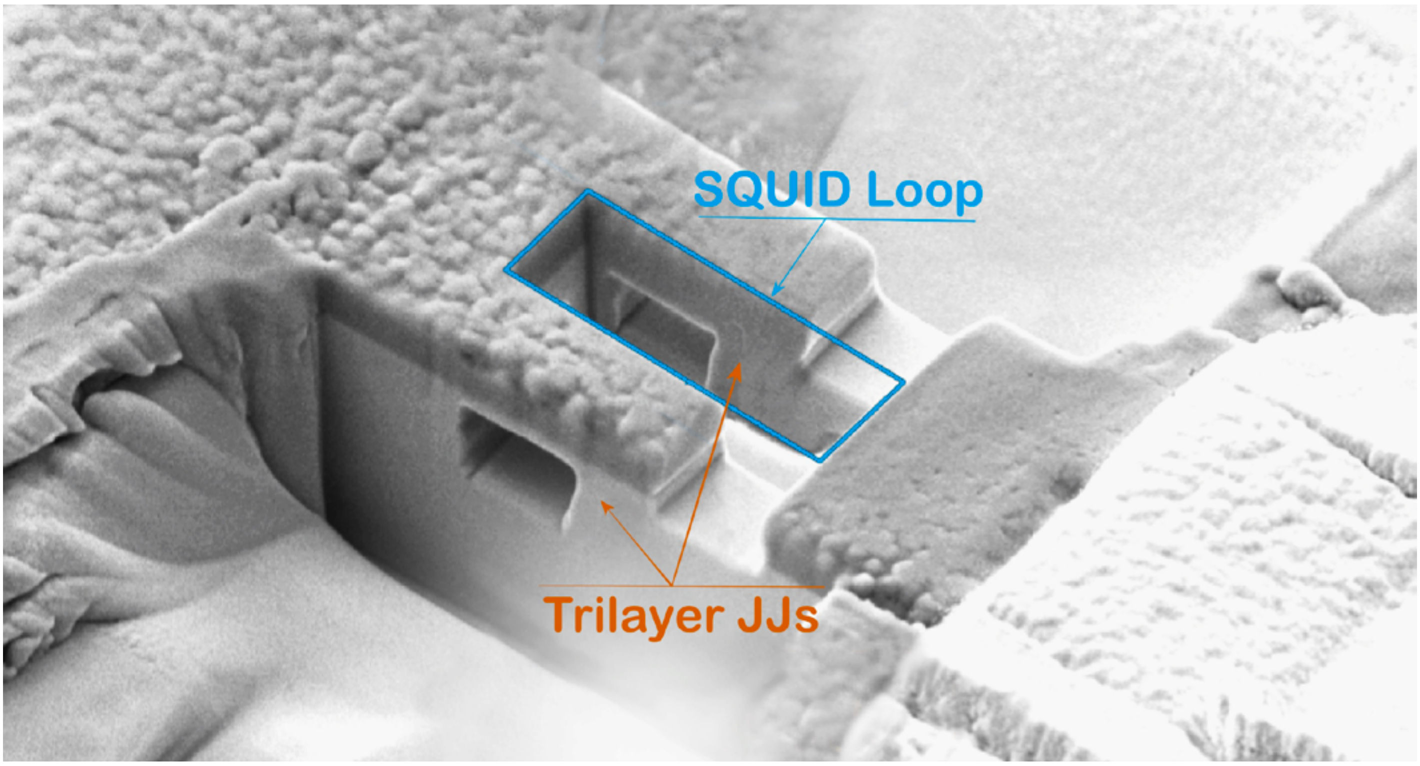


Ambature Develops Trilayer High-Temperature Superconducting Devices

The high-temperature superconductor developer Ambature, Inc. has created Josephson junctions and superconducting quantum interference devices (SQUIDs) using a-axis YBCO. The company recently demonstrated a large critical current density, indicating a robust design and an improved junction quality, important characteristics as they work towards fabricating their first magnetometers and gradiometers.

Ambature has been seeking to develop an improved Josephson junction that takes advantage of the crystallographic alignment of a-axis trilayers in the anisotropic high-temperature superconductor YBCO. The company grows a trilayer sandwich of YBCO-PBCO-YBCO, similar in structure to those found in niobium superconducting devices, using molecular beam epitaxy for an extremely high-quality material. Their paper published in APL Materials by their Cornell research partners describes the process (https://doi.org/10.1063/5.0034648).

Gold Etch Stop Layer Introduced

Ambature uses standard semiconductor cleanroom equipment to fabricate their Josephson junctions, such as sputter deposition and reactive ion etching (RIE). Recently, its research team had explored various methods of creating a via through an isolation layer without affecting the YBCO, including lift-off and RIE. They concluded that RIE etching with an etch stop layer of gold was the most robust method.

The gold etch stop layer was introduced to protect the YBCO layer from etching during the via formation and to enhance the contact quality. The new layer improved their critical current density by an order of magnitude.

Additionally, the junction area was reduced to the photolithography limit in the company's Waterloo clean room. In the future, they plan to explore electron beam lithography to further reduce the junction area. They are working to improve the contact resistance through new fabrication steps.

The team applied an external magnetic field to observe the quantum interference pattern created by critical current modulations, the Fraunhofer pattern. While an ideal Fraunhofer pattern has a larger central lobe corresponding to zero magnetic field and smaller lobes for non-zero magnetic field values, Ambature's model displayed sidelobes as large as the central lobe, possibly due to the nonuniform critical current density of the junction.

SQUIDs Fabricated with Trilayer Material

The team also fabricated SQUIDs with their trilayer material using focused ion beam (FIB) milling to sculpt SQUIDs with a loop area of 1 x 3 μm^2. While these SQUIDs were too small to have an exceptional signal-to-noise ratio, the researchers were able to measure a standard modulation curve using a physical property measurement system (PPMS) from Quantum Design. In the future, they plan to include pickup and feedback coils to improve noise and develop a magnetometer.

Based in Waterloo, Ontario and Scottsdale, Arizona, Ambature, Inc. is currently focused on designing superconducting materials and quantum devices. The company owns and offers licenses for over 200 patents, with over 3700 unique patent claims, worldwide. It had previously reported developing a-axis YBCO-PBCO-YBCO wafers that were suitable for fabricating trilayer Josephson junction devices (see *Superconductor Week*, Vol 35, No 7). ■

TERTIA Joins ICEoxford's DRY ICE Systems

UK-based specialist cryogenic systems manufacturer ICEoxford recently introduced its DRY ICE 300mk TERTIA cryostat, an upgraded version of the company's previous DRY ICE 300mk Single Shot system. TERTIA offers both single shot and continuous operation capabilities, an extended hold time of 100 hours with 7 liters of He3, a reduced recondense time of one hour, and up to ten ports for customer wiring.

"The DRY ICE 300mK TERTIA is an extension of our DRY ICE 4K system and DRY ICE 1K System whose modularity allows the systems to be upgraded," commented Cesca Molyneux, a senior marketing executive with ICEoxford. "The systems all use the same technologies to achieve some of the highest cooling powers on the market."

TERTIA is a closed-loop system that enables users to carry out experiments in a 300 mm sample plate within a temperature range from 280 mK to 425 K. The cryostat also offers a high-cooling-power capability of 50 μW at 285 mK and100 μW at 295 K.

TERTIA Uses ICE Sock Technology

The system is capable of achieving ±1 mK, maintaining temperature stability at 300 mK and above, and has a cool-down time of 22.5 hours to base temperature. It was originally developed for Professor Seamus Davis whose field of research is macroscopic quantum matter at the University of Oxford, University College Cork and Cornell University. It offers a combination of specifications that couldn't be found in any other system on the market.

TERTIA uses ICEoxford's ICE Sock technology. The cryocooler sits supported within a cold AV frame "sock" which separates the system's two cold-heads from the cryostat. This reduces the vibration levels at the sample space to about 20 nm, with additional options available to reduce these levels to less than 10 nm.

ICE Sock technology also helps to counteract high vibration levels, which means that TERTIA can take advantage of Gifford-McMahon (GM) cryocooler technology; GM is

▸ lower cost than pulse-tube refrigerator cooling. The ICE Sock technology also allows for the easy removal of the cold head, eliminating the requirement for a remote motor.

TERTIA Offers a Range of Magnets

ICEoxford offers a range of magnets with the TERTIA: solenoid, split-pair and vector rotate magnets up 18 T. All of the company's magnets incorporate twisted filaments to maximize magnetic stability and minimize magnetic hysteresis.

The magnets also incorporate high-temperature superconductor current leads to allow for fast magnet ramping and minimize heat generation. They deploy wire bonded in an epoxy matrix to prohibit movement and prevent premature quenching.

ICEoxford's Vector Rotate Magnet is a cryogen-free 2-axis superconducting magnet with customized Z-bore. The magnet is wound from twisted multifilamentary NbTi superconductor embedded in a copper matrix.

The Vector Rotate Magnet is able to generate a magnetic field in three discrete directions with fields up to 9/3 T for 2D and 6/3/3 T for 3D. This makes it possible to hold the sample stationary while the magnetic field is varied around it.

The homogeneity of the z-coil is ±0.1% with an approximate maximum current of 100 Amps and a cold bore of 76 mm. For the x-coil, to homogeneity is ±0.5% with an approximate maximum current of 55 Amps.

ICEoxford's Split-pair Magnet offers a cold bore and horizontal axis field. The magnet is designed with radial access ports and is wound with twisted muli-filamentary NbTi superconductor embedded in a copper matrix.

The Split-pair has a magnetic field of up to 10 T, and homogeneity of ≤0.1%, an approximate maximum current of ≤70 Amps, and a split 25.4-mm/50.8-mm cold bore. Stronger magnets are available upon request.

ICEoxford’s solenoid magnet has a magnetic field range up to 14 T and is optimized for cryogen-free operation. The magnet is wound from twisted multifilamentary NbTi/Nb3Sn superconductor wire embedded in a copper matrix.

The solenoid is designed with a persistent switch installed and has a guaranteed persistent mode drift rate under 100 ppm/hour. The system has a homogeneity of ± 0.1%, an approximate maximum current of 200 Amps, and a 50.8 mm cold bore.

TERTIA Compares Favorably to Competing Products

ICEoxford notes that the TERTIA system compares favorably to the technologies offered from the competition. Its cooling power compares to the Janis ULT’ HE-3-SSV-PT-2 which achieves 100 µW at 400 mK. The 280 mK base temperature is lower than the 310 mK for the Janis system and 415 mK for the Bluefors He3 system. The 100 hours of hold time with 7 liters of helium compares to the Janis system requiring 10 liters for the same time frame. If hold time is not a key requirement, the TERTIA can achieve 50 hours with 5 liters of helium with considerable cost savings.

“This product is still very new to the market so it’s early days,“ Molyneux said. “So far we have noticed a combination of new customers as well as customers looking to replace wet versions of this system with a newer, dry version.” ■

Tokamak Energy Builds Complete HTS Magnet Set for a Spherical Tokamak

The UK fusion development company Tokamak Energy has completed the fabrication of a unique set of 44 high-temperature superconducting pancake coils that will be assembled in the company's Demo4 device, which will demonstrate the potential of a spherical tokamak with an all REBCO magnet cage. This constitutes the first instance of the manufacture of a complete set of REBCO coils for a spherical tokamak.

The 44 individual magnetic coils were manufactured using 38 kilometers of REBCO tape supplied by four manufacturers. These HTS tapes are typically 12 mm wide and less than 0.1 mm thick.

More specifically, the magnets include 16 fully insulated poloidal field (PF) pancake coils assembled into two PF magnet coil stacks. The PF magnets were tested satisfactorily in an LN2 bath.

The remaining 28 magnets are partially insulated toroidal field (TF) pancake coils that were fabricated using Tokamak Energy's patented partial insulation technology (see *Superconductor Week*, Vol 35, No 9). The company is currently testing the individual coils in LN2 prior to assembling them into 14 TF limbs. In total, 32 TF coils will be built, which includes four spare ones.

Algorithm Balanced HTS Tape Across TF Limbs

"These are a 'world-first set' of magnets as it required a sophisticated algorithm to distribute the REBCO tape pieces across what must be a balanced set of TF limbs," commented Rod Bateman, Tokamak Energy's HTS magnet development manager. "The production of REBCO is a deposition process, and whilst this process is rapidly becoming more repeatable, there are still manufacturing variances.

"This means that, among our stock of 38 km of tapes, there was a variety of critical current performances and piece lengths. We had the Tapestar data from the manufacturers but in addition we took samples from each piece and had them evaluated as a function of temperature, field strength and field angle at RRI.

"With this and the piece length data, our algorithm was put to work to distribute the tape database across all the 32 TF coils to ensure they had an operating margin as closely matched as possible. This should ensure balanced operation both in static and transient or error condition operation."

Demo4 to Test Strong Magnetic Forces in Fusion Scenarios

The full Demo4 assembly will be completed later this year and testing will extend into 2024. Demo4 will be used to create strong magnetic forces that will be tested in fusion power plant-relevant scenarios.

Tokamak Energy will use the device to increase the technology readiness level of HTS magnets as a step towards demonstrating grid-ready fusion in the early 2030s. It is intended to inform the designs and operational scenarios for the company's advanced prototype, ST80-HTS, and the subsequent fusion power plant, ST-E1.

Tokamak Energy recently reached an agreement with the United Kingdom Atomic Energy Authority's (UKAEA) to construct ST80-HTS at the latter's Culham Campus, near Oxford, with building completion planned for 2026. ST80-HTS will target significantly longer pulse durations with the objective of reaching the sustained high power output that would be required for commercially competitive fusion power plants. The device will also inform the design of its ST-E1, which, in the early 2030s, is projected to produce up to 200 MW of net electrical power, thereby demonstrating the capability to deliver electricity into the grid. ■

NSF Awards $500,000 to FAMU-FSU for Research into Chalcogenides

The U.S. National Science Foundation (NSF) has awarded a nearly $500,000 grant to the FAMU-FSU College of Engineering to develop superconducting materials with high magnetic resistance. The funding will allow researchers to explore the extent to which superconducting chalcogenides synthesized out of niobium, palladium, and either sulfur or selenium withstand magnetic inference.

Transition metal chalcogenides comprise superconducting phases with high critical temperatures, such as iron and molybdenum chalcogenides. The research effort focuses on new ternary and quaternary niobium and tantalum chalcogenides, with some of these phases showing unconventional superconductivity with very large critical fields.

Project Aims to Push the Boundary of High Magnetic Superconductivity

The metal chalcogenide to be investigated is a Type II superconductor, which means it can tolerate some interference from magnetic fields. It keeps its superconducting properties even with interference from magnetic fields four times greater than leading theories predict, making it an intriguing target for further investigation.

"If we understand why this is happening, then we can start to think about engineering other types of materials, where we can go to higher magnetic fields and still maintain superconductivity," said Theo Siegrist, FAMU-FSU Researcher who is Principal Investigator on the project. "We'd like to understand the origin of this behavior.

"Is there a microscopic origin? What does it depend on? Can it be engineered? Can it be changed? We don't really understand why it's doing it, but now we have a way of tweaking it and interrogating the system to see how it responds."

Palladium Levels May Influence Magnetic Interference

The researchers will grow crystals made of those compounds and examine them using x-rays to investigate their structures and how those structures correspond to their ability to withstand interference. The exact chemical mixture of the compound can contain varying amounts of palladium and of sulfur or selenium. Previous research from Siegrist's team showed that the amount of palladium affects its ability to withstand magnetic interference.

Critically important to the research will be the synthesis and growth of high quality samples for a detailed understanding of structure-property relationships. Structural characterization using diffraction techniques will be combined with investigations of physical properties, including magnetic susceptibility, electronic transport properties, and optical properties. Furthermore, tuning of the physical properties by a combination of chemical substitutions and stoichiometry variations will be explored. ■

EU Funds SCARLET to Commercialize Long-distance Superconductor Transmission

The EU's Horizon Europe program has awarded €15.0 million ($16.0 million) in funding for the Superconducting Cables for Sustainable Energy Transition (SCARLET) program for a period of 4.5 years through Grant Agreement No. 101075602. SCARLET unites 15 partner organizations around the goal of designing and industrially manufacturing superconducting cables in kilometric lengths. The project brings together industrial partners Absolut System, ASG Superconductors, Nexans, RINA Consulting, SuperGrid Institute, SuperNode, and Vision Electric Super Conductors as well as the research institutes and universities ESPCI, the Research Institute for Sustainability (RIFS), RSE SpA, SINTEF, the IEE Slovak Academy of Sciences, the University of Bologna, and WavEC.

"This is an opportunity and now our responsibility to bring this new power cable technology to commercial performance levels," said Niklas Magnusson, Project Coordinator from SINTEF Energy Research in Norway. "We will enable the supply of renewable energy to Europe at a significantly lower cost than what is possible today."

SCARLET to Develop 1 GW Cable Systems

Rising amounts of renewable energy coupled with an increase in decentralized power generation call for the modernization and extension of the European grids. Recent studies have shown that European transmission corridors with lengths of several hundred kilometers and capacities of 5 to 20 GW are needed. SCARLET aims to develop 1 GW cable systems and bring them to the type test stage, the last qualification step before a commercial installation.

"The main SCARLET work packages are related to long-length onshore cables, offshore cables, hydrogen-cooled cables, and system protection," said Adela Marian, senior researcher at RIFS in Potsdam, Germany. "They are complemented by the work package on integration and economic studies.

"The main milestones are related to designing and manufacturing the components of the cable system in order to have a high-performance cable sample available for the type test. SCARLET will use two conductor materials for the cable demonstrations: HTS operating in liquid nitrogen at 67 K and MgB_2 operating in liquid hydrogen at 20 K.

"The cable systems will be tested on industrial test platforms. For the hydrogen-cooled cable there will be an additional long-term field test carried out in an external field for hydrogen testing available at Absolut System."

SCARLET Tech Designed for MVDC Operation

Marian explained that an entire work package will be dedicated to offshore superconducting links with offshore cooling systems: "The design of the offshore cooling systems will take into account the technical and economic limits associated with superconducting, cryogenic, and offshore technologies along with the stakeholder needs and requirements derived from current industry knowledge. At the moment we are at the beginning of this iterative process.

"In any case, as a general remark, the SCARLET technologies are designed for MVDC operation, which is enabled by the high-current capability of superconductors. This eliminates costly high-voltage converter stations and allows for significant overall cost reductions.

"This is particularly interesting for offshore applications, as it leads to smaller and much less expensive equipment at offshore wind power farms. The partners involved in the offshore work package

▸ are Nexans, SuperNode, WavEC, Absolut System, and SINTEF."

SCARLET to Develop Hydrogen-cooled Superconducting Cables

Another work package is focused on hydrogen-cooled superconducting cables. Such cables would open up the unique possibility of simultaneously transporting both hydrogen and electricity.

"Using hydrogen as a coolant enables so-called dual distribution systems, where both electricity and hydrogen are delivered in the same pipeline to end users," said Marian. "This is particularly relevant for transportation systems and the energy-intensive metallurgical industry, where both electrical and chemical energy are needed.

"The main challenge arises from the combination of high voltage and liquid hydrogen, which needs to be carefully considered when developing the components of the cable system such as high-voltage insulation, terminations, and cooling system.

"Throughout the project, procedures will be defined for the safe design, operation and performance of the cable system in liquid hydrogen, based on safety rules recommended in standards. The partners involved in the development of hydrogen cooling systems are ASG Superconductors, Absolut System, and RINA Consulting."

SCARLET Involves End Users at Early Stage

SCARLET is designed to involve the end-users of superconducting cable systems at an early stage of development. Their needs and perspectives as well as practical knowledge will be integrated into the project through the establishment of an Advisory Group.

"The Advisory Group will be composed of external experts covering all of the relevant perspectives related to the superconducting technologies developed in SCARLET," said Marian. "This will ensure relevance to a wide spectrum of end users and useful feedback throughout the project."

The inclusion of end users from an early stage will ensure that the developed technologies are relevant to a broad spectrum of users. Moreover, the testing experience gathered in SCARLET will contribute to the development of a first set of recommendations for the HVDC superconducting standard of the future. To this end, a working group will be established, possibly within the framework of the International Council on Large Electric Systems (CIGRÉ), with a focus on testing high-power superconducting cables.

Ideally, the recommendations and testing protocols proposed by the working group will be applied and verified in SCARLET. At the end of the project, the results will be forwarded to the IEC, the international organization that prepares and publishes standards for all electrical technologies.

Within SCARLET, RIFS in Potsdam will be leading the work package on "Dissemination and Exploitation," which includes classic dissemination activities such as media reports, information events, and policy recommendations for public authorities. The activities related to stakeholder integration under the Advisory Group and standardization are also part of this work package. RIFS recently launched SCARLET's website at https://scarlet-project.eu/. ■

MIT-led Team Identifies Switchable Superconductivity in Magic-angle Graphene

Researchers with the Massachusetts Institute of Technology (MIT), the Weizmann Institute of Science, and the National Institute for Materials Science in Japan have identified superconductivity in magic-angle graphene that can be turned on and off with an electric pulse (doi.org/10.1038/s41565-022-01314-x). The discovery could lead to ultrafast, energy-efficient superconducting transistors for neuromorphic devices, which are electronics designed to operate in a way similar to the rapid on/off firing of neurons in the human brain.

Magic-angle graphene refers to a particular stacking of graphene in a hexagonal pattern resembling chicken wire. When one sheet of graphene is stacked atop a second sheet at a precise 'magic' angle, the twisted structure creates a slightly offset superlattice that is able to support a host of surprising electronic behaviors.

“There is a lot of interest in switchable bistable devices for memory and computing applications that aim to replicate the way the brain works,” said Dahlia Klein, a researcher at the Weizmann Institute of Science and lead author of the paper. “These often use ferroelectric materials. Our devices exhibit ferroelectric-like switching of their electronic state, with the special characteristic that the low resistance state is actually a superconducting state.

“This is something very unusual and although, for now, we are mostly interested in the basic physics of these devices. There is the potential to use these novel bistable superconducting devices in novel applications related to neuromorphic computing that could use this novel functionality, for example superconducting quantum computing or superconducting memories.”

“There is a growing number of superconducting devices made from magic-angle graphene including Josephson junctions, diodes, and SQUIDs,” said MIT Professor Pablo Jarillo-Herrero. “This bistable magic-angle graphene could be incorporated into future 2D materials-based superconducting circuits as a superconducting memory element or other element requiring an on/off switch.”

Magic-angle Graphene Identified at MIT in 2018

Magic-angle twisted bilayer graphene was first demonstrated at MIT in 2018. At the time it was observed that the bilayer structure could behave as an insulator when a certain continuous electric field was applied. However, when this field was increased the material morphed into a superconductor. The discovery was a watershed in the field of twistronics, which explores how certain electronic properties emerge from the twisting and layering of two-dimensional materials.

MIT researchers have continued to reveal new properties in magic-angle graphene, including various ways to switch the material between different electronic states. So far, such switches have acted more like dimmers, in that researchers must continuously apply an electric or magnetic field to activate and maintain superconductivity.

The recent MIT-lead study has shown that superconductivity in magic-angle graphene can be switched on, and kept on, with a short pulse rather than a continuous electric field. The key is a combination of twisting and stacking.

The discovery was made after the research team stacked magic-angle graphene between two offset layers of boron nitride, a two-dimensional insulating material. The unique alignment of the sandwich structure enabled the researchers to turn graphene’s superconductivity on and off with a short electric pulse.

Research Builds on 2019 Stanford Study

In 2019, a team at Stanford University discovered that magic-angle graphene could be coerced into a ferromagnetic state. The researchers found that magic-angle graphene could exhibit ferromagnetic properties in a way that could be tuned on and off.

▸ This happened when the graphene sheets were layered between two sheets of boron nitride such that the crystal structure of the graphene was aligned to one of the boron nitride layers.

In the current study researchers fabricated a sandwich of carefully angled and stacked materials. The center of the sandwich consisted of magic-angle graphene - two graphene sheets, the top rotated slightly at the magic angle of 1.1 degrees with respect to the bottom sheet.

Above this structure, they placed a layer of boron nitride, exactly aligned with the top graphene sheet. Finally, the researchers placed a second layer of boron nitride below the entire structure and offset it by 30 degrees with respect to the top layer of boron nitride.

The team then measured the electrical resistance of the graphene layers as they applied a gate voltage. They found, as others have, that the twisted bilayer graphene switched electronic states, changing between insulating, conducting, and superconducting states at certain known voltages.

Electronic State Unexpectedly Persists without Voltage

What the group did not expect was that each electronic state persisted rather than immediately disappearing once the voltage was removed, a property known as bistability. They found that, at a particular voltage, the graphene layers turned into a superconductor, and remained superconducting, even as the researchers removed this voltage.

"After the pulse is removed, the system stays in its superconducting state over long time scales," said Klein. "The longest measured is for about one day, but presumably it could last for much longer.

"The device's superconducting properties are similar to that of conventional, non-switchable magic-angle graphene. For the hole-side superconducting region, T_c is 2.15 K, I_c is 50 nA, and the B_{c_perp} is 25 mT (approximate, taken at 65 mK). For the electron-side superconducting region, the superconductivity is weaker with a T_c of 0.83 K, an I_c of 15 nA, and a B_{c_perp} of 3 mT (approximate, taken at 65 mK)."

It isn't clear what enables this switchable superconductivity, though the researchers suspect it has something to do with the special alignment of the twisted graphene to both boron nitride layers, which enables a ferroelectric-like response of the system. The research team sees the new superconducting switch as another tool to deploy as they develop materials for faster, smaller, more energy-efficient electronics.

Other 2D Superconducting Materials may also Exhibit Bistable Behavior

"Currently, this bistable behavior arising from top and bottom Boron-Nitride alignment has only been observed in untwisted bilayer graphene (to switch between metallic and insulating states) and magic-angle graphene in this work," said Klein. "Since this switchable behavior originates from this unique double alignment, it is unclear whether other 2D superconducting materials, which are not graphene-based, could be switched in a similar way, though we suspect this is likely the case.

"The bistable behavior in our device does not affect the properties of magic-angle graphene. Therefore, the device is still limited by its T_c which restricts it to cryogenic applications.

"There are ongoing efforts to uncover the microscopic origins of how the double alignment gives rise to the bistable behavior in these systems. These insights could help us understand how to engineer the alignments for faster switching or apply this principle to other 2D tunable systems."

The work received support from the Air Force Office of Scientific Research, the Army Research Office, and the Gordon and Betty Moore Foundation's EPiQS Initiative. ■

AMSC Grid Revenues Lower in Q3 FY2022

AMSC has announced in its Q3 FY2022 earnings release that Grid unit revenues fell by 17.1% to $20.8 million, compared to $25.1 million in revenues realized in Q3 FY2021. The net operating loss of the segment was $7.1 million, compared to a loss of $3.7 million during the comparable period in the previous year. The decline in revenues were primarily driven by lower non-superconducting D-VAR sales during the period.

For the first three quarters of FY2022, Grid unit revenues declined by 9.4% to $66.3 million from the $73.2 million achieved during the first three quarters of 2021. The net operating loss rose to $20.8 million compared to a loss of $14.9 million during the comparable period last year.

"Our third quarter revenue was driven by new energy power system shipments," commented AMSC chairman and CEO Daniel P McGahn during the quarterly earnings conference call. 'Our Grid segment revenue for the Q3 of FY2022 accounted for over 85% of AMSCs total revenue. Our backlog at the end of the third quarter increased by nearly 40%, when compared to the same quarter, a year ago."

SPS Contract Signed for LPD-32

During the earnings conference call, McGahn provided an update on AMSC's superconducting Ship Protection Systems (SPS) solution: "We announced that our SPS contract with [shipbuilder] Huntington Ingalls will be deployed on the San Antonio Class amphibious ship LPD-32. The LPD-32 contract marks AMSCs fifth ship protection system for the San Antonio class ship platform.

"Right now, we are installing our first SPS on the USS Fort Lauderdale. This is something the Navy and our shipyard partner are monitoring closely.

"We are preparing to deliver on our second ship contract, the USS Harrisburg. We currently have orders for the USS Harrisburg, the USS Pittsburgh, the USS Richard McCool, and the recently-added LPD-32.

REG Bond Returned to AMSC

McGahn noted that AMSC's Resilient Electric Grid (REG) system in Chicago continues to perform well: "We received notification from the utility that the system met the specified performance requirements, and as a result, we expect to see the return of a $5.0 million bond which was held until the REG system passed this important accomplishment. The performance bond was structured as a letter of credit, which is expected to hit our books during Q4 of FY2022.

"We continue to see strong desire from this utility, as well as others to further deploy REG into the power grid. Everything that we see, everything that we're told, everything we've been shown, leads us to believe that there's a very bright future for REG in many, many cities in the country."

Total Revenues Down During Quarter

For Q3 FY2022, AMSC's aggregate revenues, which include its Wind unit, fell by 10.8%, to $23.9 million from $26.8 million in Q3 FY2021. The company reported a net loss of $9.6 million ($0.34 per share) compared to a loss of $4.3 million ($0.16 per share) during the comparable period last year.

AMSC realized $74.2 million in revenues during the first three quarters of FY2022, 7.4% lower than the $80.1 million achieved during the first three quarters of FY2021. The company recorded a net loss of $28.2 million ($1.01 per share) compared to a net loss of $14.2 million ($0.52 per share) over the comparable period last year.

"During Q3 of FY2022, we achieved progress on our strategic priority of a more diversified business", McGahn said. "We believe we are well positioned to not only take advantage in the renewables market, but also in semiconductor, mining and materials, and defense markets.

"We booked $43.0 million of total orders, including $26.0 million of new energy power systems orders. We ended our third quarter with a backlog of over $110 million. Our pipeline of prospective orders, driven mainly by macro-trends such as climate and environmental policies, is diversified and expected to position us for future growth."

Cash, cash equivalents and restricted cash at the end of the quarter fell to $31.4 million, compared with $37.4 million at the end of the Q2 FY2022. AMSC's share price declined by 4.8%, to $5.36 from $5.63, on the day following the earnings announcement.

Higher Revenues Expected in Q3 FY2022

For Q4 FY2022, AMSC anticipates that its revenues will be in the range of $27.0 million to $30.0 million. The company's net loss for the fourth quarter of fiscal 2022 is expected not to exceed $8.0 million, or $0.28 per share.

AMSC expects operating cash flow to be a burn of $4.5 million to $6.5 million during the quarter. Cash, cash equivalents, and restricted cash are projected to be greater than $25 million on March 31, 2023. ■

Superconductor Demand Drives Bruker BEST Revenue Higher in FY2022

Bruker Corporation's Energy & Supercon Technologies (BEST) segment reported that revenue rose by 5.9%, to $237.1 million in FY2022 from $223.8 million in FY2021. Operating income was $31.3.2 million, 41.0% higher than the $22.2 million realized during the previous year. The higher sales were attributed to strong superconductor demand from MRI original equipment manufacturer customers.

"Superconductor demand appears healthy but we continue to experience supply chain challenges due to some material shortages," commented Frank Laukien, the president and CEO of Bruker during the quarterly earnings conference call. "Many of our technologies within BEST are not only used for high energy physics experiments, big science, or MRI, but increasingly also by clean tech as clean tech technologies under development. Here are examples of contracts that we have received: for over $50 million for superconducting materials from an Asian pilot plant on fusion magnetic confinement fusion, as well as from ITER indirectly, for something that is part of the diverter."

BioSpin Recognizes Revenue from Four GHz-class Insruments

The Bruker BioSpin Group reported annual revenues of $696.7 million compared to $691.0 million in FY2021, a decline of 0.8%. Operating income was $167.1 million, 5.6% higher than operating income of $158.2 million the previous year. The increase in revenue was due to strong growth in its service and support revenues, as well as strong growth in pre-clinical imaging and a notable contribution from our biopharma process analytical technology, offset by unfavorable currency impact.

"Bruker BioSpin recognized revenue on four GHz-class NMR instruments in FY2022 consistent with the four systems recognized in FY2021," Laukien said. "Customers

‣ have accepted two 1.0 GHz NMR systems in Q4 of FY2022, one at Ryokan in Japan and one in Barcelona, Spain.

"These acceptances were ahead of schedule as this new compact, single story 1.0 GHz product launch is technically going really very well. It resulted, however, in some 1.2 GHz installations moving to FY2023. And in 2023, we are expecting to install four GHz class NMR although none are expected in Q1 FY2023."

Ten Percent Organic Growth in FY2022

For the company as a whole, Bruker announced revenues of $708.4 million for Q4 FY2022, 3.6% higher than Q4 FY2021 revenues of $683.5 million. Organically, revenues increased 13.6% year-over-year. Net income was $97.4 million ($0.66 per share) compared to $75.7 million ($0.50 per share) in the comparable period, a 28.7% increase.

For FY2022, Bruker revenues were $2,530.7 million, 4.7% higher than the $2,417.9 million realized during FY2021. Net income was $296.6 million ($1.99 per share) compared to $277.1 million ($1.81 per share) during the same period last year, an increase of 7.0%. Bruker's share price rose by 3.9%, from $72.26 to $75.05, on the day following the earnings announcement.

"In FY 2022, Bruker delivered solid financial improvements, with 10% organic revenue growth, 150 bps gross margin expansion and 11% non-GAAP EPS growth," Laukien said. "Our teams achieved this despite supply chain challenges, and while making significant investments in proteomics and spatial biology. Last year, our Scientific Instruments segment [which includes Bruker BioSpin] generated double-digit organic bookings growth and built additional backlog, which gives us good visibility into FY2023."

Bruker Anticipates Higher Revenue in FY2023

Cash on the balance sheet was $645.5 million at the end of the quarter, compared to $626.2 million at the end of Q3 FY2022. Under its 2021 share repurchase program, Bruker bought back over 4.2 million shares during FY2022 for approximately $264.7 million. About $94.4 million remains available for future stock purchases.

For FY 2023, Bruker expects revenue of $2.81 to $2.86 billion, or 11% to 13% year-over-year reported revenue growth. This takes into account organic revenue growth of 8% to 10%, M&A contributions of approximately 1.5%, and a foreign currency translation tailwind of approximately 1.5%.

Bruker intends to further increase its R&D and commercial investments, particularly in proteomics and spatial biology, with FY 2023 R&D expenses of approximately 10% of revenue. The company anticipates FY2023 non-GAAP EPS of $2.52 to $2.57, or 8% to 10% year-over-year non-GAAP EPS growth. ■

KIT Develops Superconducting Gralmonium Qubit

Researchers from the Karlsruhe Institute of Technology (KIT) have fabricated what they have labeled a gralmonium qubit, consisting of a fluxonium qubit with a single layer Josephson junction (DOI: 10.1038/s41563-022-01417-9). They measured coherence times in the microsecond range and observed spontaneous jumps of the value of the Josephson energy on timescales from milliseconds to days. The gralmonium potentially could be used with hybrid architectures employing magnetic fields or serve as a diagnostic tool for microscopic defects in superconducting materials.

"In our group we are generally interested in high-impedance circuits with granular aluminum (grAl) and have a long history of work on this," commented KIT researcher Dennis Rieger, co-leading author of the study. "See for example: "Loss Mechanisms and Quasiparticle Dynamics in Superconducting Microwave Resonators Made of Thin-Film Granular Aluminum" (DOI: 10.1103/PhysRevLett.121.117001), "Granular aluminium as a superconducting material for high-impedance quantum circuits" (doi.org/10.1038/s41563-019-0350-3), and "Implementation of a Transmon Qubit Using Superconducting Granular Aluminum." The gralmonium is a combination of all granular grAl elements in one circuit and layer and, in addition, it constitutes the smallest grAl element to date: the grAl nano- junction. "

The Josephson effect has been a key contributor to the advancement of superconducting technology for quantum information processing. The vast majority of Josephson junctions are in the form of Al/AlOx/Al superconductor-insulator-superconductor (SIS) weak links. SIS links have the advantage of providing control over the insulating barrier, thermal cycling robustness, and strong coherence.

"The Josephson energy for a standard SIS tunnel junction is typically a very stable parameter defined by the area of the junction and the oxidation process," Rieger noted. "For this reason, standard mesoscopic tunnel junctions do not typically show the spontaneous jumps leading to frequency jumps in the qubit spectrum."

Yet because of the necessary multi-layer and often multi-angle evaporation processes, it is difficult to decrease the size of SIS junctions to a level below 100 × 100 nm^2, The critical current is therefore suppressed in a Fraunhofer pattern for magnetic fields in the 102 mT range.

Furthermore, the junction's parallel plate electrodes store energy. Removing these could result in an increase in the total energy passing through the junction. Other types of weak links, such as super-/semi-/superconductor junctions or constructed superconducting wire (ScS) Josephson junctions, address some of the shortcomings associated with SIS junctions but also have their own drawbacks.

The KIT team's gralmonium qubit combines the attractive coherence of an SIS junction with the nanoscopic, single-layer design of an ScS junction. They used a self-structured aluminum grain assembly of granular aluminum (grAl) to form a nano-junction, which they incorporated into a superconducting fluxonium qubit. This configuration enabled them to fabricate the whole circuit as a single layer, since they could tailor the geometry of the wires to engineer all the components for qubit and readout.

"The fluxonium an ideal testbed for the nano-junction, which is intrinsically protected by the superinductor connecting to it," Rieger said. "Imagine that there is a 'discharge' across the junction; the large inductance helps to limit the voltage across it.

"In contrast, in a transmon, large capacitor pads would be connected to the junction. This would even favor the occurrence of discharges, which will drop right across the junction and can even 'short circuit' it. In fact, this behavior already occurs for conventional SIS tunnel junctions when they are small; it is difficult to protect them.

▸ "We can use the flux as a knob to tune the qubit frequency and measure the spectrum of the qubit. By checking if the qubit crosses the readout resonator frequency, we have a rapid test to select working devices.

"Moreover by fitting the spectrum vs. flux, we directly learn about the current-phase-relation of the nano-junction and can compare it to the one of a standard tunnel junction. In a transmon, we would have to measure many levels to be able to learn about the current-phase- relation."

Using spectroscopy, the researchers found that the gralmonium grAl nano-junction demonstrated Josephson energy similar to conventional qubit Josephson junctions. Coherence times of about 10μs also corresponded to SIS junctions. The absence of parallel plate electrodes reduced capacitance, which suggests that the gralmonium could be an appealing alternative for high impedance circuits where large quantum fluctuations of the phase are sought.

The research team also noted that the gralmonium's nanoscopic footprint, along with its μs coherence times, makes it a useful resource for seemingly contradictory reasons. On one hand, a reduced susceptibility to external magnetic fields allows the use of the grAl nano-junction in hybrid architectures employing magnetic fields. On the other hand, the greater susceptibility of the junction to microscopic defects and nearby noise makes it a sensitive detector for superconducting materials.

Rieger noted how the KIT team plans to continue its work: "We currently have two follow-up plans. One priority is to learn more about the unconventional Josephson energy/criticial current fluctuations of the nano-junction. And secondly, we want to measure the gralmonium in large magnetic fields to see how it performs."

Funding for this research was provided by the Alexander von Humboldt foundation in the framework of a Sofja Kovalevskaja award endowed by the German Federal Ministry of Education and Research and by the European Union's Horizon 2020 program under No. 899561 (AVaQus). ■

Superconducting Humor

Currents

Conectus, the CONsortium of European Companies Determined To Use Superconductivity, has announced that it will present its first Awards for Students and Early Career Professionals at EUCAS 2023 as a way to recognize, appreciate and support the activities of young people devoted to applied superconductivity. The awarded candidates will receive a certificate, a superconducting medallion and a financial award: first place €1,000, second place €500, and third place €250.

The awards committee is accepting nominations from the superconductor community by email until June 9. Nomination criteria and information that must be included in an email submission can be found at https://www.conectus.org/conectus-award/

Bluefors, the Finnish manufacturer of cryogenic measurement systems, is acquiring the U.S. cryocooler technology company Cryomech. The deal is expected to close by the end of March. The combined company will have close to 600 employees in Finland, Germany, the Netherlands, and the United States, per the Cryomech announcement.

The financial terms of the acquisition agreement were not disclosed. The Committee for Foreign Investment in the United States (CFIUS) has approved the transaction. The shareholders of Cryomech's employee stock ownership plan (ESOP) also need to give their assent before the completion of the transaction.

Once the acquisition is completed, the combined company will use the Bluefors name. Cryomech will become a product brand, with no changes to its existing products and services portfolio. Cryomech's management team will remain in place, and current company president Rich Dausman, will join the Bluefors board of directors as an observer.

The superconducting quantum computing company Rigetti Computing, Inc. has announced that its board has approved an updated business strategy, including revisions to its technology roadmap. In connection with this plan, the company will transition to a newly appointed CFO and CTO and is implementing a workforce reduction in order to focus the organization and its resources on nearer-term strategic priorities.

Under its mew roadmap, Rigetti will seek to deliver its anticipated Ankaa-1 84-qubit system in Q1 FY2023. Ankaa-1 will feature denser qubit spacing and tunable couplers that are expected to enable better performance compared to Rigetti's current 80-qubit Aspen-M system.

The company will also prioritize increasing the performance of the anticipated Ankaa-1 system once it is launched with the goal of reaching at least 99% 2-qubit gate fidelity. If this target is achieved, Rigetti plans to shift its focus to scaling to develop the anticipated Lyra 336-qubit system.

With regard to leadership changes, Jeffrey Bertelsen is replacing Brian Sereda as CFO. Bertelsen previously worked as the CFO of CyberOptics Corp. alongside current Rigetti CEO Subodh Kulkarni.

In addition, David Rivas was promoted to CTO, replacing Mike Harburn, Rivas previously served as Rigetti's Senior Vice President, Systems and Services since March 2019, overseeing the engineering and operations of Rigetti's Quantum Cloud Services platform.

The company also announced a 28% headcount reduction in order to lower operating expenses in activities outside of its focus areas and preserve available cash resources. The new roadmap and headcount reduction come towards the end of a tumultuous first year for Rigetti as a publicly-traded company, with its share price that falling from over $10.00 to under $1.00 and the departure of company founder Chad Rigetti.

The quantum computing startup PsiQuantum has announced the opening of a UK-based advanced R&D facility at the Daresbury Lab in northwest England, run by the Science and Technology Facilities Council of United Kingdom Research and Innovation (STFC UKRI). This effort is receiving £9.0 million ($10.7 million) of funding from the UK government's Department for Science, Innovation and Technology (DSIT), and will give the company access to one of Europe's largest liquid-helium cryogenic plants.

PsiQuantum will work with Daresbury scientists who are specialized in large-scale cryogenic infrastructure to develop the advanced cryogenic systems necessary to scale photonic quantum computers to millions of qubits. The collaboration will have the objective of delivering quantum computing modules capable of delivering 100 W of cooling power at liquid-helium temperatures.

PsiQuantum is building an error-corrected quantum computer which harnesses the quantum mechanical properties of photons. Similar to superconducting qubit technology, photons require cryogenic cooling but at a less demanding level. The company's approach uses superconducting nanowire single-photon detectors (SNSPDs) to read the state of the photonic qubits.

The 16th European Conference on Applied Superconductivity, EUCAS 2023, will be held in Bologna, Italy on September 3-7, 2023. Conference registration opened on March 1. The announced plenary speakers are William Oliver, MIT; Aldo Di Zenobia, ENEA; Teresa Puig, ICMAB; Seungyong Hahn, Seoul National University; Eddie O'Connor, SuperNode Ltd.; and Ziad Melhem, Quantum Solutions Ltd. Further information about the conference can be found at https://eucas2023.esas.org/.

Technical staff at the U.S. Department of Energy's Fermi National Accelerator Lab (Fermilab) have completed a prototype of a special superconducting cryomodule that will be incorporated into the Proton Improvement Plan II, or PIP-II. The new high-beta 650 MHz (HB650) is the longest and largest cryomodule in PIP-II. Ultimately, four of them will comprise the last section of the new linac that will upgrade Fermilab's accelerator complex.

The HB650 cryomodule is a 10-meter-long cylinder, weighing approximately 27,500 pounds. At its core is a chain of cavities made of superconducting niobium. The cavities are shielded by a vacuum jacket consisting of mylar multi-layer insulation, an aluminum thermal shield, and another coat of mylar multi-layer insulation. A carbon steel vacuum vessel encapsulates all of these layers.

The HB650's final design review occurred in 2020; procurement for many of its components began shortly afterward. Assembly started in January 2022 in a new cryomodule assembly facility.

Upon its completion last month, the prototype was moved from its assembly location to a testing complex on Fermilab's campus, where it will undergo a series of checks to validate its design and functionality. The PIP-II cryogenic team has begun the process of cooling down the prototype to 2 K to test its resilience. Following cool-down, the team will perform a transportation test in which they ship the cryomodule to PIP-II partners in the United Kingdom.

Once the HB650 prototype has been validated, the four cryomodules will be built by PIP-II's global partners. Three will come together at Daresbury Lab, run by the Science and Technology Facilities Council of United Kingdom Research and Innovation (STFC UKRI).

The fourth will be assembled at Fermilab, using components provided by the Raja Rammana Center's for Advanced Technology of India's Department of ▸ Atomic Energy. Ten low-beta 650-MHz cryomodules that make up the penultimate stage in the linac will later be built by collaborators at the French Alternative Energies and Atomic Energy Commission (CEA).

These superconducting cryomodules will power beams of protons to the final energy of 800 MeV, before the protons exit the linac. From there, the beam will transfer to the upgraded Booster and Main Injector accelerators, where it will gain more energy before being turned into a beam of neutrinos. These neutrinos will then be sent on a 1,300-kilometer journey through earth to the Deep Underground Neutrino Experiment and the Long Baseline Neutrino Facility in Lead, South Dakota.

QuantWare, a Netherlands-based provider of large-scale superconducting quantum processors, has launched Tenor, a new processor featuring scalable technology and enabling quantum computers with 64 fully controllable qubits to be built commercially. The company has developed a patented 3D technology that routes the qubit connections vertically, which they claim makes it possible to scale superconducting quantum processors to thousands of qubits. Tenor is the first device commercially available that features this technology.

Because QuantWare's qubits are fully controllable, its processors are suitable for error-correction schemes. Such a design requires more connections per qubit than the more common fixed frequency qubits, and as such were impossible at a scale of 64 qubits with conventional planar devices.

QuantWare's aim is to become the "Intel of quantum computing" by providing easy-to-use, increasingly powerful, and affordable quantum processors. It is seeking to bring its technology to the market at a ten-times lower price point than competing solutions.

The experimental high-energy physicist and emeritus professor Roy Schwitters passed away last month. Born in Seattle in 1944, he received his doctoral degree from the Massachusetts Institute of Technology and was a professor at Harvard and Stanford Universities before joining the faculty of the University of Texas in Austin part-time in 1990 while working as a director on the Superconducting Super Collider and full time after 1993. Prior to his retirement in 2020, Schwitters was the S.W. Richardson Foundation Regental Professor of Physics and spent time as chair of the Department of Physics.

In 1974, while working a founding member of the Collider Detector at Fermilab, Schwitters co-discovered a new particle, the charm quark, at the same time that the Samuel Chao Chung Ting group at Brookhaven National Lab made the same observation. In 1976, Richter and Ting were awarded the Nobel Prize in Physics for the discovery.

The Chinese firm Origin has made its superconducting 24-qubit Wuyuan quantum computer available for real-world applications business and academic customers. This makes China along the U.S. and Canada as the only known countries to have utilized this technology on an applicable scale. Wuyuan uses an unspecified number of quantum processing units (QPUs), but comes with a custom operating system, and a cloud-computing platform, allowing Chinese businesses to hire the computer as they would any HPC cloud-computing instance.

Origin is working on a more powerful quantum computer called Wukong, that is to be released at an unspecified time in the near future. Curiously, in the ongoing chip dispute between U.S. and China, Origin hasn't been blacklisted from using U.S. quantum computing technologies, suggesting that perhaps Origin's technology is wholly its own.

ASG Superconductors (ASG) and Siemens Healthineers have signed a partnership agreement to synergistically develop ultra-high field MRI systems. Their first project is to be the delivery of a 10.5 T MRI system to the Hefei University of Technology in China.

The magnet will be built and comprehensively tested at ASG's premises in Genoa. Upon its arrival in Hefei, Siemens Healthineers will be responsible for the integration and installation of the system.

Quantum Exponential Group Plc, a company focused on investing in quantum technology, has appointed Stuart Woods as its chief operating and strategy officer. Woods is expected to lead company efforts to capitalize on the investment opportunities presented by quantum sensing, quantum timing, quantum networking, and quantum computing.

Woods most recently served as managing director of Oxford Instruments NanoScience, a division of Oxford Instruments Plc, where he led a team working to develop and commercialize quantum computing, and create high performance cryogenic and cryogen-free environments for ultra-low temperature and high magnetic field applications in physics, chemistry and materials science research. He was interviewed last year as part of our Spotlight series in *Superconductor Week*, Vol 36, No 4.

Oxford Instruments Plc has signed licensing and sponsored research agreements with the Applied Superconductivity Center (ASC) of the The National High Magnetic Field Lab (MagLab) to explore magnet technology based on superconducting Bi-2212. The agreements focus the collaboration on research with commercial potential while providing new training opportunities and prospective career paths for students and post-doctoral students studying Bi-2212.

“We started studying Bi-2212 in the 1990s and returned to it again around 2007 because of its unique geometry,” explained MagLab’s Chief Materials Scientist David Larbalestier. “In 2014, a discovery that the overpressure processing we had used for another bismuth-based conductor could be applied to Bi-2212 was game changing in yielding the kinds of critical current density that make this conductor’s applications very exciting.”

The South African alternative and renewable energy company Renergen recently announced that it had successfully produced both liquefied natural gas (LNG) and liquid helium from the Phase 1 pilot plant of its Virginia Gas Project (VGP). It is now planning the construction of Phase 2, which will be a significantly larger plant.

Upon completion, Renergen expects the Virginia project will deliver a substantial amount of energy to the South African economy, while also transforming the country into one of the world’s largest helium exporting countries. Given the potential production capacity of both Phases, current favorable high energy prices, the current demand environment, the weaker South African rand relative to the U.S. dollar, and other current macro-economic indicators, the company’s objective is to deliver an estimated EBITDA of between R5.7 billion ($310.0 million) and R6.2 billion ($340.0 million) per year once the plants are in full production, which is not anticipated to be before FY2027.

The Phase 1 pilot plant is designed to produce a maximum of 2,700 GJ of LNG and about 350 kg of liquid helium a day. Renergen anticipates that Phase 2 will produce about 34,400 GJ of LNG and about 4,200 kg of liquid helium a day in its first full financial year of production.

A final investment decision on Phase 2 is expected to be made in the second half of this year. If the project moves forward, Renergen is expected to achieve debt financing approval of up to $500 million from the U.S. International Development Finance Corporation and up to $250 million from a mandated global bank.

Spotlight

Dr. Nicholas Long is the director of the Paihau-Robinson Research Institute

Superconductor Week (SW): Let's begin with a brief introduction of who you are, how you got started in your career, and how you wound up at Robinson.

Nicholas Long (NL) : Sure. I'm Professor Nicholas Long. I grew up near Wellington, in a more provincial area, but I went to the Victoria University of Wellington as an undergraduate, got a master's degree there, and then went to the University of Southern California for my doctoral studies. I spent five and a half years in Los Angeles and studied condensed matter physics - so low-temperature physics - universal conductance fluctuations, specifically, which is a phenomenon of quantum interference of conduction electrons that occurs at low temperatures. When I finished my PhD, I looked around for jobs back in New Zealand, as I wanted to come back for family reasons.

There was a group here at the site working on superconductivity, and at that stage they were part of a government organization called Industrial Research Limited, which operated much like a U.S. National Lab such as Oak Ridge or Lawrence Berkeley. They had gotten into superconductivity back when the first discoveries were made with high temperature superconductors, and a small group of people here made some key discoveries, particularly in the BSCCO (Bi-Sr-Ca-Cu-O) system. Out of that they developed a relationship with American Superconductor (AMSC) that lasted for many years. So I joined the group in late 1994 after finishing my PhD. When I initially joined I didn't work on superconductors, I was working on oxygen ion conductors for oxygen separation for about two or three years. Then after that project ended I started working with American Superconductor and the wide development project that we had with them.

That lasted a good many years and we worked on a lot of interesting problems, many of them around BSCCO manufacturing, and troubleshooting some of the issues they had with that - blisters and balloons caused by chemical impurities or unwanted chemical phases that you have in the BSCCO material as it is developed. I also worked on creating new parting agents with them, which are coatings that prevent the wire from all sticking together during the heat-treating process. As American Superconductor switched to the coated conductors, we switched with them, and booted up a program working on the metal organic deposition of superconductors. We had a program here working on different pinning additions, making changes in the chemical composition for the metal organic precursors and seeing what differences those made in the pinning performance and the I_c (critical current) performance.

I also was part of a small group looking at AC conductors. We independently considered developing Roebel cables out of the coated conductors; we thought we were the first but it turned out that Siemens had actually patented that idea.

‣ SW: Can you explain what a Roebel cable is?

NL: Sure. A Roebel cable is a 100 year old technology that essentially takes bars of conductor, or relatively flat conductors, and transposes them into a twisted cable.

There are copper Roebel bars which are used in large generators and transformers, and essentially you take two stacks of copper bars and interlace them to cross each other at regular intervals, so that the conductors rotate through all positions in the stacks as they go along. That gives every conductor an equivalent electromagnet environment averaged out over the length of the cable, which maximizes current capacity and avoids large loops of eddy currents - that is why it was invented. Roebel is the name of the German engineer who came up with that idea for large electrical machines. He realized that if you have AC machines with very large conductors, you are going to keep having these coupling currents, and you can't just take single wires and keep scaling them up indefinitely because the AC losses become prohibitive. Instead, you have to subdivide and transpose the conductor. So a superconducting Roebel cable does exactly the same thing.

The catch is that you can't bend these coated conductors; you have to punch out the material, so we had to develop a fine blanking process to punch the material out from a wider conductor. Then, you have to be careful with the machines that actually wind it all together, because the conductor is relatively fragile. We started a program on that here in about 2004 and we put in a patent application, but it turned out Siemens had actually trumped us on that. We worked, nonetheless, with Siemens on a large generator project at the time to put a Roebel cable into the rotor windings of a generator - such as for hydro power plants, or possibly even nuclear power plants. The idea was to fit the conventional rotors with superconducting rotors and get a performance and efficiency benefit out of doing it. That project was roughly from 2008-2010.

Unfortunately the state of wire manufacturing at that stage just wasn't mature enough to deliver the volume and quality of wire required, and the cost of the Roebel cable was prohibitively expensive given the wasted material from the fine blanking process. The economics didn't look that great, so that program never reached demonstration stage. Nonetheless, we did do a small demonstration of Roebel cables in an 1 MVA transformer with funding from the New Zealand government, and that showed significant AC loss mitigation.

A bit later, we got involved with a Chinese project to design superconducting transformers for high-speed rail, where the application of a superconducting Roebel cable in the windings makes sense. The transformer has not actually been built as of yet, as far as I know, and I suppose that will depend on their ability to procure wire of the right quality and volume. Regardless, a good design was done which showed that it would work, and would substantially reduce the weight and volume, and increase the power output from the onboard traction transformer for their high speed trains.

So, besides all of our Roebel cable research, our group has also done a lot of work on coated conductors, and we additionally built some of the world's first MRI systems using ReBCO.

SW: That was a Robert Slade project, right?

NL: Yeah that's right, Robert Slade and Ben Parkinson led that project. I wasn't particularly involved due to my focus on the Roebel cable projects and the pinning work we did with American Superconductor. Anyways, I had been promoted to Deputy Team Leader by 2014, and at that stage the government institute that we were part of, Industrial Research Limited (IRL), got reorganized into a new government organization called Callaghan Innovation. As part of that transition, we became a materials and engineering institute within the Victoria University of Wellington here. I think it's been a positive change; it's meant we've had more of an educational mission, with lots more PhD students joining us. We still bid for the same government grants within New Zealand, so our funding base hasn't changed that much. In November 2016, our former director, Bob Buckley, retired from his position to get back into the lab and work more with students, and I took over as director of the Institute.

▸ Of course, we get some income from the PhD students on the teaching side, and we can still work commercially either with New Zealand companies or with international groups, as we had previously done. We've gone from about 25 people, two of whom were PhD students, to 90 total in the Institute, about 30 of whom are students. We have half a dozen administrative staff, and the rest are technical staff from professors and senior scientists, early career researchers and highly skilled technicians. We have quite a lot of autonomy in what we choose to do, and we've grown quite a bit since we switched over.

In the New Zealand context, we can't only do superconductivity; it's too narrow to be sustainable here. We've always done some other materials work, such as with magnetic materials and sensors; we developed a non-destructive testing technology with magnetic sensors. I'm doing a bit of work now on magnetic materials for electric vehicle charging; we've got a joint project with the University of Auckland investigating magnetic composites to go into charging pads or onboard electric vehicles.

We've also got a large project right now on a fairly novel topic for us. One of our researchers was looking at the magnetic separation of minerals and out of that he developed an interest in hydrogen processing of New Zealand's iron sand resources. We have a steelmaking industry here based on volcanic iron sand, and the project seeks to use hydrogen rather than carbon (in the form of coal) to process this resource, which aligns well with carbon dioxide emissions reduction.

Our Institute has been able to thrive by aligning itself with what the New Zealand government wants and what society wants, so in superconductivity we are very active in the development of high power-to-weight-ratio motors for electric aircraft. New Zealand is very actively looking at the options for electric aircraft and alternative fuel sources, so there's sort of pull there from the airlines. On the international side, we're working with Raytheon Technologies on their program as well. This is part of a true international effort to create superconducting motors for larger scale electric aircraft that seat up to 200 passengers, which are much harder to electrify than two-seater type aircraft.

We've also become much more active in space research. New Zealand has become involved in space somewhat by accident, you might say. Peter Beck, who interestingly was also a member of IRL, and actually worked with us on the Roebel cable project, and designed the first machines for punching and winding Roebel cable, left around 2009 to form Rocket Lab (https://www.rocketlabusa.com/). He has obviously been extremely successful, and Rocket Lab has had an incredible trajectory of growth and success. Out of that, New Zealand formed a space agency and realized it could make an economic success out of space activity. Unfortunately, however, New Zealand didn't have any research capability in space, or at least very limited capability, so the government has lately tried to nurture some. Out of that, we've gotten some research funds to do superconductor-enabled ion thruster technology for electric propulsion in space; it's called an "applied field magneto plasma dynamic thruster."

SW: We just published an article about it!

NL: Indeed. That project is going very well, and we are scheduled to put a superconducting magnet on the ISS in 2024.

SW: How will that be delivered? From where?

NL: It's usually the astronauts who take it directly to the space station in a suitcase, as far as I understand. The astronauts literally put it in a box, like a suitcase, and carry it onto the space station.

SW: Do you know where the launch will take place?

NL: I don't know that, but we are working with a Houston-based group, Nanoracks (https://nanoracks.com/). They have a contract with NASA to do these commercial add-ons to the space station program. So I don't yet know where the launch will be from, but it will be on a mission where they are taking up new astronauts and bringing down the old ones.

SW: Great. Since we are on the topic of the Paihau-Robertson Research Institute itself, lets discuss its history a bit more. Who was Bill Robinson? Why is the organization named after him? And what does the Maori word "Paihau" mean?

▸ NL: So just before 2014, when we knew we were transferring to the university, we had the chance to choose a name. Bill Robinson was a New Zealand engineer who worked for the precursor to IRL, actually a government research laboratory, DSIR, and at that stage he was an administrator in charge of the Physics and Engineering Laboratory. So he was at least administratively involved in setting up the superconductivity activity, but more relevantly he was very passionate about engineering for public benefit. His most famous invention is actually that of earthquake dampeners, which are deployed both here in Wellington and in different places around the world that suffer from seismic activity. He designed several earthquake dampening systems, and set up a company to make them. Unfortunately, he first suffered a stroke and then passed away in 2013, and his company was sold to another international company. The technology is still out there, and if you park at our hospital in Wellington or visit the national museum you can actually see the dampeners under the buildings. Earthquakes are a big issue here, as you might be aware, so protecting buildings is a big deal.

SW: These dampeners allow buildings to shake during an earthquake?

NL: They are a combination of lead and rubber which are able to passively absorb a lot of the sideways movement in the building. Bill did a lot of other research as well. He had many close friends here at the Institute, so people were very happy to name it after him.

Then, the Māori name: in New Zealand it's very common for public organizations to have both an English name and a Māori name. Victoria University of Wellington, for example, also has the Māori name of Te Herenga Waka. you go to their website there's also this name. The Māori name is usually a bit more metaphorical, and Te Herenga Waka refers to a place where you tie up your canoe; it's saying the university is somewhere where everybody comes on a journey, meeting other people and leaving as a graduate.

Our name, Paihau, has an explicit meaning, but it also has a metaphorical meaning. Explicitly it refers to the extended sides of a traditional Maori canoe, the Waka.

SW: The stabilizing arms that stick out of the sides of a canoe?

NL: Paihau refers to wood sections on each side which are jointed to the main body of the waka, or canoe. They run in the same direction as the main body of the waka and extend its length forwards. It is a piece of engineering that stabilizes the bow of the canoe and extends its length. Paihau also has a metaphorical meaning, that of a kind of breath or spirit. We chose this name because it explicitly refers to a bit of engineering, but also because of this idea of extending the organization, being a leading edge, and purposefully carrying an additional load into the future.

SW: Are public-private partnerships in New Zealand significantly different than in the United States, for example?

NL: No, I think it's broadly very similar to the United States and Europe. The government has various funds that we can apply to, some of which are more fundamental and some of which are more applied. The larger funds are for the applied programs, and there we have to make the case that research will benefit New Zealand. The benefit can be environmental or social, but for us it usually means there has to be some economic benefit, so we have to argue that either some existing industry or some new industry will emerge that can use this technology to create jobs, create exports and so on.

I think we've had a very positive economic impact in New Zealand to date. In 2004, we spun out HTS 110, a small magnet company that has been very successful making BSCCO magnets, and lately, ReBCO magnets; we still collaborate with them on the development of new projects. We also do a lot of work with Fabrum Solutions (https://fabrum.nz/), they are another New Zealand company active in cryogenics and superconductivity-adjacent work. They began with their expertise in glass fiber reinforced composites, so we use them for developing composite cryostats of various sorts and composite motor components. They have been partners with us on multiple projects, and they've grown a lot over the years. They make cryocoolers for liquid nitrogen production, their process for which originally came out of the larger group at Industrial Research Limited.

SW: Why did the IRL's incorporation into the university happen when it did?

NL: It really came out of the senior government, the equivalent of what you'd call a Cabinet Minister for Science and Innovation, or whatever their title was. They made a decision that the organization as a whole, IRL, wasn't delivering value for money, but they realized that our superconductivity and chemical groups had international reputations and good commercial activity. So the question was where to find the best place to put us within the New Zealand system, preserve what we had, and allow us to grow. They thought it was best for us as an institute to move to the university, and I believe that was the right decision. We had a strong enough science base that we could compete with other university groups for funding. We also had high publication rates, and so we were able to compete strongly in an academic context.

SW: Do you think the incorporation in the university system has led to more students selecting superconductivity as a field of research? Other than Robinson, I don't know what other options are available to interested Kiwis.

NL: It has certainly provided more opportunities for those students, but more importantly it's our responsibility to get the message out about the opportunities we present; at the moment in New Zealand, the labor market is really strong for science and engineering students. Rocket Lab is still growing and hiring people, and there are other aerospace companies doing the same. Healthcare companies also make a lot of use of physics.

The opportunities are there. New Zealand has traditionally been a low-tech, agriculturally-based economy, and it's only in the last twenty to thirty years that all of these technology firms have popped up. They have to be a bit like Rocket Lab where they are internationally connected and competitive right away.

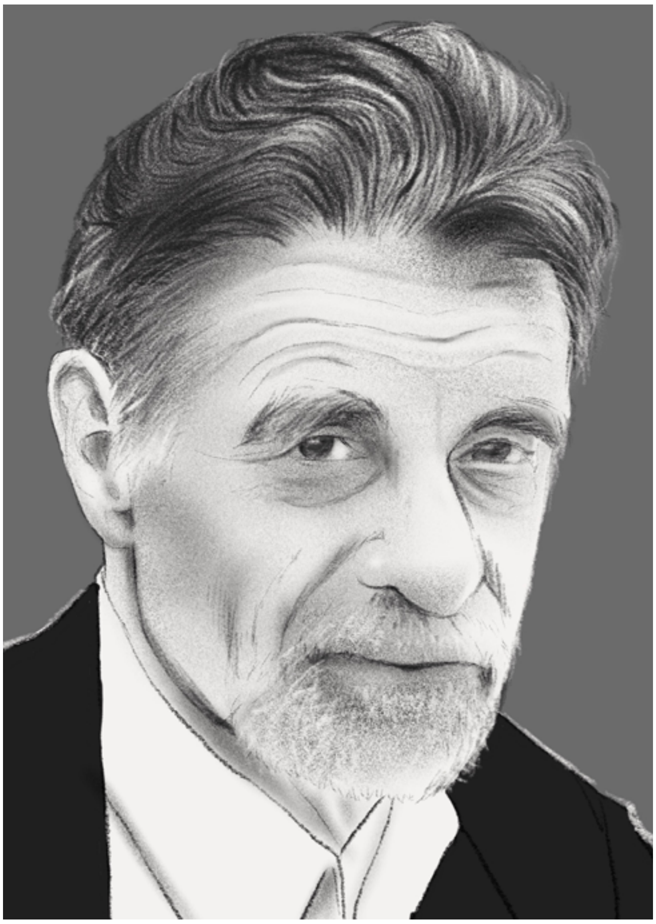
It's been a very positive change - we get a lot of undergraduate summer students here out of the university interning and taking summer courses. Of course, a lot of New Zealand students like to go overseas for their graduate studies, and not everybody is going to stay around here. The very best students like to see if they can get into the Harvards and Stanfords of course, or go to the UK and try for Cambridge and Oxford. But then, some of those same people come back as well, which is great. We've been able to hire some very good people recently out of NASA's Jet Propulsion Laboratory, which has really strengthened our space activity; we also hired a senior magnet engineer out of MagLab in Florida, and that's bolstered our confidence in the high field magnet area.

SW: Great. I would say it's a testament to New Zealand that its been able to make that kind of transition. A lot of countries have never been able to go from an agricultural base to a high tech economy. It requires the collaboration of the state education system, universities, private companies - a pretty complicated feat.

NL: I think New Zealand has also benefited greatly from the internet revolution. During COVID times we were no different from anywhere else. Nobody was traveling, everyone was just working on ZOOM, so nobody cared that we were in New Zealand as long as we got the times right. In that sense, it's a good time to be working here. When I applied to graduate school in the United States it was all by paper, you had to fill out forms and send them, and submitting papers was all done manually. All the diagrams had to be done as photographs, and you put it all in an envelope and sent it off to London or New York or wherever.

SW: Thanks for all the great information! ■

Luminary



Karl Alexander Müller 1927-2023

At a young age, Karl moved with his parents to Salzburg, where his father studied music. A short time later, the family moved to Dornach, to be near his grandparents.

Müller's mother passed away when he was only 11. In 1938, he attended a boarding school at the Evangelical College in Schiers, where he would remain until 1945. It was here that he developed his love for alpine skiing, and spent much of his free time building and repairing radios - at the time, he wanted to become an electrical engineer. One of his tutors, however, pushed him towards physics, and he never looked back. He received his baccalaureate in 1945 and thereafter completed his compulsory military service.

Müller then attended the physics and math department at the Swiss Federal Institute of Technology, where he was mentored by Wolfgang Pauli, a then-recent Nobel Prize laureate. He would eventually meet Bednorz there too, as his PhD advisor. He was part of the "atom bomb semester", as shortly after the U.S. used nuclear weapons in Japan there was a surge of interest in nuclear physics.

As an undergrad, Müller studied the Hall effect in gray tin. He got his diploma and worked for a year at the department of industrial research at ETH, where his work was centered around Eidopher large-scale displays, a type of projector.

The following year he returned to ETF Zürich to get his PhD and subsequently married Ingeborg Louise Winkler. His son Eric was born in 1957 and his daughter Eric, in 1960. After submitting his thesis in 1957, Müller went on to the Battele Memorial Institute in Geneva, where he was put in charge of a magnetic resonance group, while he simultaneously delivered lectures at the University of Zürich.

In 1963, IBM offered him a research position at their Zürich lab (ZRL), where he would remain until retirement. Much of his time at IBM was sent investigating the properties of strontium titanate and related perovskite compounds. He studied their photochromic properties when doped with transition-metal ions. In 1970 he juggled this work along with a full-time professorship at the University of Zürich.

Müller was put in charge of the ZRL physics department from 1972 to 1985. In 1982 he was named as an IBM Fellow, and it was around this time he began his investigation of high temperature superconductivity. He had invited Bednorz to join him at IBM, where they tested various oxides for superconductivity. The two tested materials that were considered so unorthodox that they kept it a secret from their colleagues, afraid that they would be laughed at.

In 1986, Müller and Bednorz achieved superconductivity with LBCO at just over 35 K, a significant jump from the previously recorded high temp of 23 K. Their discovery prompted a surge of related study. Their findings were published in the Zeitschrift für Physik B and, only a few months later, Paul Chu at the University of Houston achieved a transition temperature of 93 K in YBCO. BSSCO was developed around the same time.

In 1987 Müller and Bednorz were awarded the Nobel Prize - the shortest time between discovery and award in Nobel history.

Müller passed away in 2023 at an assisted living facility. He continued alpine skiing until well into his 80s. He didn't believe that his research should be limited by convention or popular theory. Famously, he once said, "I don't talk to theoreticians. They just hold me back." ■

Patents

Method For Preparing Compact Of Resin Compound Having Anisotropy
Niigata University
Shin-etsu Chemical Co., Ltd.
January 3, 2023
U.S. Patent No. 11,541,580
A method for preparing a compact of resin compound comprising the following steps (a) to (c): (a) a preparation step of mounting a sheet-shaped or block-shaped compact of resin compound including a resin composition, which contains a filler having magnetic anisotropy and is solidified by curing or by being advanced to a B-stage, on a transportation unit which is movable in the horizontal direction, and covering at least a top surface of the compact of resin compound with a cover material; (b) a step of applying a magnetic field to the compact of resin compound obtained in the step (a) with a bulk superconductor magnet having a central magnetic flux density of 1 T or more; and (c) a step of moving the compact of resin compound in the horizontal direction and scanning it while applying vibrations to the compact of resin compound mounted on a region of a central part of the bulk superconductor magnet under application of a magnetic field.

Superconductive Circuit Splitter Placement
Microsoft Technology Licensing LLC
January 3, 2023
U.S. Patent No. 11,544,438
A system and method for placing Josephson junction splitters on a superconducting circuit layout receives a specification of locations to be connected by a number of Josephson transmission lines. The system determines, based on the specification, a topology specifying connections between the locations, the topology including a plurality of 1-to-2 Josephson junction splitter nodes. The system determines splitter node locations based at least on ranges determined from distances between adjacent range endpoints of a previous level of the topology, and the system places each of the 1-to-2 Josephson junction splitter nodes at the determined splitter node locations.

Controlling A Quantum Computing Device Based On Predicted Operation Time
IBM Corp.
January 3, 2023
U.S. Patent No. 11,544,613
Systems, computer-implemented methods, and computer program products that can facilitate determining a state of a qubit are described. According to an embodiment, a system can comprise a memory that stores computer executable components and a processor that executes the computer executable components stored in the memory. The computer executable components can comprise a relation determining component that can determine relation of a status signal of a quantum computing device to a noise value of the quantum computing device. The system can further include an operation time estimator that can estimate an operation time for the quantum computing device based on the relation of the status signal to the noise value.

Superconducting Current Control System
Northrop Grumman Systems Corp.
January 3, 2023
U.S. Patent No. 11,545,288
One example includes a superconducting current control system. The system includes an inductive coupler comprising a load inductor and a control inductor. The inductive coupler can be configured to inductively provide a control current from the control inductor to superconducting circuit device based on a load current being provided through the load inductor. The system also includes a current control element comprising a superconductor quantum interference device (SQUID) array comprising a plurality of SQUIDs. The current control element can be coupled to the inductive coupler to control an amplitude of the load current through the load inductor, and thus to control an amplitude of the control current to the superconducting circuit device.

Reducing Dissipation And Frequency Noise In Quantum Devices Using A Local Vacuum Cavity
Google LLC
January 3, 2023
U.S. Patent No. 11,545,288
A device includes: a substrate including a superconductor quantum device, the superconductor quantum device including a superconductor material that exhibits superconducting properties at or below a corresponding critical temperature; a cap layer bonded to the substrate; and a sealed cavity between the cap layer and the substrate.

Current Biased Tunable Qubit
IBM Corp.
January 3, 2023
U.S. Patent No. 11,545,974
Techniques for designing, creating, and utilizing a current biased tunable qubit are presented. A qubit device can comprise a first Josephson junction (JJ) located along a first current path of the device, and a second JJ and third JJ coupled in series along a second current path in parallel with the first current path, wherein the second and third JJs facilitate controlling frequency of the device. The first JJ can be larger in area than each of the second and third JJs, wherein a current splitting ratio between the first current path and second current path can be increased thereby. The device can comprise a capacitor with a first terminal associated with the second and third JJs, and a second terminal associated with ground. Alternatively, a high kinetic inductance wire can be used in the first current path, instead of the JJ.

High Density Microwave Hermetic Interconnects For Quantum Applications
IBM Corp.
January 10, 2023
U.S. Patent No. 11,551,125
A quantum computer includes a refrigeration system under vacuum including a containment vessel, a qubit chip contained within a refrigerated vacuum environment defined by the containment vessel. The quantum computer further includes a plurality of interior electromagnetic waveguides and a plurality of exterior electromagnetic waveguides. The quantum computer further includes a hermetic connector assembly operatively connecting the interior electromagnetic waveguides to the exterior electromagnetic waveguides while maintaining the refrigerated vacuum environment. The hermetic connector assembly includes an exterior multi-waveguide connector, an interior multi-waveguide connector, and a dielectric plate arranged between and hermetically sealed with the exterior multi-waveguide connector and the interior multi-waveguide connector. The dielectric plate permits electromagnetic energy when carried by the interior and exterior pluralities of electromagnetic waveguides to pass therethrough.

Quantum Computing Device Model Discretization
Microsoft Technology Licensing LLC
January 10, 2023
U.S. Patent No. 11,551,130
A computing device including memory storing a quantum computing device model. The quantum computing device model may include a plurality of quantum computing device components having a respective plurality of actual boundaries. The computing device may further include a processor configured to generate a first discretized model of the quantum computing device model. The first discretized model may indicate a respective estimated boundary for each quantum

computing device component. The processor may be further configured to solve a first differential equation discretized with the first discretized model. The processor may be further configured to generate a second discretized model of a focus region of the quantum computing device model. In the second discretized model, the focus region may have the estimated boundary computed for the focus region in the first discretized model. The processor may be further configured to solve a second differential equation discretized with the second discretized model.

Superconductor Wire Based On MgB_2 Core With AI Based Sheath And Method Of Its Production
Ustav materlalov a mechaniky strojov SAV
Electrotechnicky ustav SAV
January 10, 2023
U.S. Patent No. 11,551,832
The sheath is a material, which includes an aluminium (Al) matrix, in which nanometric aluminium oxide particles (Al2O3) are homogenously dispersed, the content of Al2O3 is 0.25 to 5 vol. % and the balance is Al. It is preferred that Al2O3 originates from the surface layer present on Al powder used as feedstock material for consolidation. The superconductor based on magnesium diboride (MgB_2) core is fabricated by powder-in-tube or internal magnesium diffusion to boron technology, while the tube is the Al+Al2O3 composite, which is a product of powder metallurgy. A loose Al powder is pressed by cold isostatic pressing, and then the powder billet is degassed at elevated temperature and under vacuum, and then is hot extruded into a tube. A thin diffusion barrier tube filled up with a mixture of Mg and B powders or Mg wire surrounded with B powder is placed into the Al+Al2O3 composite tube under inert gas or vacuum. Such composite unit is cold worked into a thin wire and then annealed at 625-655° C for 8-90 minutes, what results in a formation superconducting MgB_2 in a wire's core.

Thermal Buses For Cryogenic Applications
Siemens Healthcare Ltd.
January 10, 2023
U.S. Patent No. 11,551,841
A superconducting magnet device including a plurality of superconducting magnet coils; a structural element mechanically and thermally linked to respective magnet coils to retain them in respective relative positions; and a cooling station thermally connected to a cryogenic refrigerator and to the structural element. A thermally conductive path, which passes through the structural element, is established between the cryogenic refrigerator and the superconducting magnet coils through the structural element.

Superconducting Magnet Apparatus
Japan Superconductor Technology Inc.
RIKEN
January 10, 2023
U.S. Patent No. 11,551,842
To provide a superconducting magnet apparatus with a structure which can prevent an increase in apparatus size even when a number of connection portions serving to connect superconducting wires is great. The superconducting magnet apparatus includes a first wiring-holding portion (tubular body) extending from a bobbin in an axial direction of a superconducting coil and a second wiring-holding portion (joint plate) which is provided on a same side in the axial direction as the tubular body, extends in a direction intersecting with the axial direction, and has a greater diameter than that of the bobbin (6) and the tubular body. Superconducting wires which extend from the superconducting coil and connect to one another are spirally wound on the tubular body and fastened to a groove formed on the joint plate.

Method For Magnetizing A Superconductor Bulk Magnet, With Generating An Auxiliary Magnetic Field In The Superconductor Bore
Bruker Switzerland AG
January 10, 2023
U.S. Patent No. 11,551,843
A superconductor bulk magnet magnetizing method providing a more homogenous trapped magnetic field includes: placing the bulk magnet inside a charger bore of an electrical charger magnet; placing a field correction unit inside a superconductor bore of the bulk magnet; applying an electrical current to the charger magnet, to generate an externally applied magnetic field, wherein a temperature Tbulk of the bulk magnet exceeds a bulk magnet critical temperature T_c;

applying an auxiliary electrical current to the field correction unit, thus generating an auxiliary magnetic field applied to the bulk magnet from within the superconductor bore, wherein Tbulk>T_c; lowering Tbulk below T_c; turning off the electrical current at the charger magnet, wherein Tbulk<T_c, and turning off the auxiliary electrical current at the field correction unit, wherein Tbulk<T_c; and removing the bulk magnet from the charger bore while Tbulk<T_c.

Superconducting Qubit Capacitance And Frequency Of Operation Tuning
IBM Corp.
January 10, 2023
U.S. Patent No. 11,552,236
A method for adjusting a resonance frequency of a qubit in a quantum mechanical device includes providing a substrate having a frontside and a backside, the frontside having at least one qubit formed thereon, the at least one qubit comprising capacitor pads; and removing substrate material from the backside of the substrate at an area opposite the at least one qubit to alter a capacitance around the at least one qubit so as to adjust a resonance frequency of the at least one qubit.

Grain Size Control Of Superconducting Materials In Thin Films For Josephson Junctions
IBM Corp.
January 10, 2023
U.S. Patent No. 11,552,237
A superconducting circuit includes a Josephson junction device including a lower superconducting material layer formed on a substrate and a junction layer formed on the lower superconducting material layer. The superconducting circuit also includes an upper superconducting material layer formed over the junction layer. At least the lower superconducting material layer comprises grains having a size that is larger than a size of the Josephson junction.

Systems And Methods For Qubit Fabrication
New York University
January 10, 2023
U.S. Patent No. 11,552,238
A method of fabricating a superconducting-semiconducting stack includes cleaning a surface of a substrate, the substrate comprising a group IV element; depositing an insulating buffer layer onto the substrate, the insulating buffer layer comprising the group IV element; depositing a p-doped layer onto the insulating buffer layer; depositing a diffusion barrier onto the p-doped layer; and processing the superconducting-semiconducting stack through dopant activation.

Superconducting Qubit And Resonator System Based On The Josephson Ring Modulator
IBM Corp.
January 10, 2023
U.S. Patent No. 11,552,239
A superconducting quantum mechanical device includes first, second, third and fourth Josephson junctions connected in a bridge circuit having first, second and third resonance eigenmodes. The device also includes first and second capacitor pads. The first and second capacitor pads and the bridge circuit form a superconducting qubit having a resonance frequency corresponding to the first resonance eigenmode. The device further includes first and second resonator sections. The first and second resonator sections and the bridge circuit form a resonator having a resonance frequency corresponding to the second resonance eigenmode. The device also includes a source of magnetic flux arranged proximate the bridge circuit. The source of magnetic flux is configured to provide, during operation, a magnetic flux through the bridge circuit to cause coupling between the first, second and third resonance eigenmodes when the third resonance eigenmode is excited.

Levitation, Guidance And Propulsion Integrated Superconducting Magnetic Levitation Train
Southwest Jiaotong University
January 10, 2023
U.S. Patent No. 11,552,580
A superconducting magnetic levitation train includes a frame, an arm, a first support member, a Dewar, a permanent magnet track, an iron core, a coil, a DC power supply system, and a second support member. the arm is arranged on a

bottom of the frame; the Dewar with bulk superconductors or superconducting magnets inside is arranged on the bottom of the frame; a bottom of the first support member and the second support member is fixedly arranged on a ground; the permanent magnet track is arranged on the first support member; the iron core is arranged on the second support member; the coil is sleeved on the iron core; and levitation, guidance and propulsion integrated superconducting magneti c levitation train further comprises a direct current (DC) power supply system to supply power to the coil.

Superconducting Output Amplifier Including Compound DC-SQUIDs Having Both Inputs Driven By An Input Signal Having The Same Phase
Microsoft Technology Licensing LLC
January 10, 2023
U.S. Patent No. 11,552,610
Superconducting output amplifiers (OAs) including compound direct current-superconducting quantum interference devices (DC-SQUIDs) having both inputs driven by an input signal having the same phase and related methods are described. An example superconducting OA includes: (1) a first compound DC-SQUID having a first DC-SQUID and a second DC-SQUID, and (2) a second compound DC-SQUID having a third DC-SQUID and a fourth DC-SQUID. The superconducting OA includes a first driver configured to receive a single flux quantum (SFQ) pulse train and amplify a first set of SFQ pulses associated with the SFQ pulse train to generate a first signal for driving the first DC-SQUID and the second DC-SQUID. The superconducting OA further includes a second driver configured to receive the SFQ pulse train and amplify a second set of SFQ pulses associated with the SFQ pulse train to generate a second signal for driving the third DC-SQUID and the fourth DC-SQUID.

Quantum Code For Reduced Frequency Collisions In Qubit Lattices
IBM Corp.
January 17, 2023
U.S. Patent No. 11,556,769
A quantum computer includes a quantum processor that includes a first plurality of qubits arranged in a hexagonal lattice pattern such that each is substantially located at a hexagon apex, and a second plurality of qubits each arranged substantially along a hexagon edge. Each of the first plurality of qubits is coupled to three nearest-neighbor qubits of the second plurality of qubits, and each of the second plurality of qubits is coupled to two nearest-neighbor qubits of the first plurality of qubits. Each of the second plurality of qubits is a control qubit at a control frequency. Each of the first plurality of qubits is a target qubit at one of a first target frequency or a second target frequency. The quantum computer includes an error correction device configured to operate on the hexagonal lattice pattern of the plurality of qubits so as to detect and correct data errors.

Superconducting Parametric Amplifier Neural Network
Massachusetts Institute of Technology
January 17, 2023
U.S. Patent No. 11,556,769
In some embodiments, a superconducting parametric amplification neural network (SPANN) includes neurons that operate in the analog domain, and a fanout network coupling the neurons that operates in the digital domain. Each neuron is provided one or more input currents having a resolution of several bits. The neuron weights the currents, sums the weighted currents with an optional bias or threshold current, then applies a nonlinear activation function to the result. The nonlinear function is implemented using a quantum flux parametron (QFP), thereby simultaneously amplifying and digitizing the output current signal. The digitized output of some or all neurons in each layer is provided to the next layer using a fanout network that operates to preserve the digital information held in the current.

Josephson Voltage Standard
Government of the U.S., as represented by the Secretary of Commerce
January 17, 2023
U.S. Patent No. 11,557,708
A Josephson voltage standard includes: electrical conductors that receive bias currents and radiofrequency biases; a first Josephson junction array that: includes a first Josephson junction and produces a first voltage reference from the first bias current and the third bias current; a second Josephson junction array in electrical communication with the first Josephson

junction array and that: includes a second Josephson junction; receives the second bias current; receives the third bias current; receives the second radiofrequency bias; and produces a second voltage reference from the second bias current and the third bias current; a first voltage reference output tap in electrical communication with the first Josephson junction array and that receives the first voltage reference from the first Josephson junction array such that the first voltage reference is electrically available at the first voltage reference output tap; and a second voltage reference output tap.

Quench Protection In Superconducting Magnets
Tokamak Energy Ltd.
January 17, 2023
U.S. Patent No. 11,557,893
A method of protecting a superconducting magnet from quenches, the superconducting magnet having at least one primary coil comprising high temperature superconductor, HTS, material. A secondary HTS tape is provided, the secondary HTS tape being in proximity to and electrically insulated from the primary coil, and being configured to cease superconducting at a lower temperature than the primary coil during operation of the magnet. A loss of superconductivity in the secondary HTS tape is detected. In response to said detection, energy is dumped from the primary coil into an external resistive load.

Reducing Parasitic Interactions In A Qubit Grid For Surface Code Error Correction
Google LLC
January 24, 2023
U.S. Patent No. 11,562,280
Methods and systems for performing a surface code error detection cycle. In one aspect, a method includes initializing and applying Hadamard gates to multiple measurement qubits; performing entangling operations on a first set of paired qubits, wherein each pair comprises a measurement qubit coupled to a neighboring data qubit in a first direction; performing entangling operations on a second set of paired qubits, wherein each pair comprises a measurement qubit coupled to a neighboring data qubit in a second or third direction, the second and third direction being perpendicular to the first direction, the second direction being opposite to the third direction; performing entangling operations on a third set of paired qubits, wherein each pair comprises a measurement qubit coupled to a neighboring data qubit in a fourth direction, the fourth direction being opposite to the first direction; applying Hadamard gates to the measurement qubits; and measuring the measurement qubits.

Production Method For MgB_2 Superconducting Wire Rod Superconducting Coil And MRI
Hitachi Corp.
January 24, 2023
U.S. Patent No. 11,562,836
The present invention is intended to increase the critical current density of a wire rod having a shape with good symmetry such as a round wire or a square wire by making use of mechanical milling method. The production method of the present invention for the MgB_2 superconducting wire rod comprises a mixing process of preparing a powder by adding a solid organic compound to a magnesium powder and a boron powder and then applying an impact to the powder to prepare a mixture of the powder in which boron particles are dispersed inside magnesium particles, a filling process of filling a metal tube with the mixture, an elongation process of elongating the metal tube filled with the mixture and a heat treatment process of heat-treating the metal tube to synthesize MgB_2.

Hybrid Superconducting Magnetic Device
Mio Smes Ltd.
January 24, 2023
U.S. Patent No. 11,562,841
A hybrid superconductive device for stabilizing an electric grid comprises (a) a magnetic core arrangement at least partially carrying an AC winding the AC winding connectable to an AC circuit for a current to be limited in the event of a fault; (b) at least one superconductive coil configured for storing electromagnetic energy; the superconductive coil magnetically coupled with the core arrangement and saturating the magnetic core arrangement during use. The hybrid superconductive device further comprises a switch unit preprogrammed for switching electric current patterns corresponding to the following modes: at least partially charging the superconductive coil; a standby mode when the

superconductive coil is looped back; and at least partially discharging the superconductive coil into the circuit. Optionally, hybrid superconductive device comprises at least one passage located within said magnetic flux. The passage conducts a material flow comprising components magnetically separable by said magnetic flux.

Epitaxial Josephson Junction Transmon Device
IBM Corp.
January 24, 2023
U.S. Patent No. 11,563,162
Devices, systems, methods, computer-implemented methods, apparatus, and/or computer program products that can facilitate an epitaxial Josephson junction transmon device are provided. According to an embodiment, a device can comprise a substrate. The device can further comprise an epitaxial Josephson junction transmon device coupled to the substrate. According to an embodiment, a device can comprise an epitaxial Josephson junction transmon device coupled to a substrate. The device can further comprise a tuning gate coupled to the substrate and formed across the epitaxial Josephson junction transmon device. According to an embodiment, a device can comprise a first superconducting region and a second superconducting region formed on a substrate. The device can further comprise an epitaxial Josephson junction tunneling channel coupled to the first superconducting region and the second superconducting region.

Highway Jumper To Enable Long Range Connectivity For Superconducting Quantum Computer Chip
IBM Corp.
January 31, 2023
U.S. Patent No. 11,568,296
According to an embodiment of the present invention, a quantum processor includes a qubit chip. The qubit chip includes a substrate, and a plurality of qubits formed on a first surface of the substrate. The plurality of qubits are arranged in a pattern, wherein nearest-neighbor qubits in the pattern are connected. The quantum processor also includes a long-range connector configured to connect a first qubit of the plurality of qubits to a second qubit of the plurality of qubits, wherein the first and second qubits are separated by at least a third qubit in the pattern.

Spinel Superconducting Tunnel Junction For Quantum Devices
Google LLC
January 31, 2023
U.S. Patent No. 11,568,299
Superconducting tunnel junctions for use in, for instance, quantum processors. In one example, a quantum processor can have at least one qubit structure. The at least one qubit structure includes a first aluminum layer, a second aluminum layer, and a crystalline dielectric layer disposed between the first aluminum layer and the second aluminum layer. The crystalline dielectric layer includes a spinel crystal structure.

Reducing Loss In Stacked Quantum Devices
Google LLC
January 31, 2023
U.S. Patent No. 11,569,205
A device includes: a first chip including a qubit; and a second chip bonded to the first chip, the second chip including a substrate including first and second opposing surfaces, the first surface facing the first chip, wherein the second chip includes a single layer of superconductor material on the first surface of the substrate, the single layer of superconductor material including a first circuit element. The second chip further includes a second layer on the second surface of the substrate, the second layer including a second circuit element. The second chip further includes a through connector that extends from the first surface of the substrate to the second surface of the substrate and electrically connects a portion of the single layer of superconducting material to the second circuit element.

Superconducting Qubit Device Packages
Santa Clara
January 31, 2023
U.S. Patent No. 11,569,428
One superconducting qubit device package disclosed herein includes a die having a first face and an opposing second face, and a package substrate having a first face and an opposing second face. The die includes a quantum device

including a plurality of superconducting qubits and a plurality of resonators on the first face of the die, and a plurality of conductive pathways coupled between conductive contacts at the first face of the die and associated ones of the plurality of superconducting qubits or of the plurality of resonators. The second face of the package substrate also includes conductive contacts. The device package further includes first level interconnects disposed between the first face of the die and the second face of the package substrate, coupling the conductive contacts at the first face of the die with associated conductive contacts at the second face of the package substrate.

Superconducting Switch
PsiQuantum Corp.
January 31, 2023
U.S. Patent No. 11,569,816
The various embodiments described herein include methods, devices, and circuits for reducing switch transition time of superconductor switches. In some embodiments, an electrical circuit includes: (i) an input component configured to generate heat in response to an electrical input; and (ii) a first superconducting component thermally-coupled to the input component. The electrical circuit is configured such that, in the absence of the electrical input, at least a portion of the first superconducting component is maintained in a non-superconducting state in the absence of the electrical input; and, in response to the electrical input, the first superconducting component transitions to a superconducting state.

Superconducting Exclusive-OR (XOR) Gate System
Northrop Grumman Systems Corp.
January 31, 2023
U.S. Patent No. 11,569,821
One example describes a superconducting XOR-gate system. The system includes a pulse generator configured to generate a decision pulse. The system also includes an input superconducting XOR-2 gate that receives a first superconducting logic input signal and a second superconducting logic input signal and is configured to perform a logic XOR function based on the decision pulse on a given phase of a clock signal to provide an intermediate superconducting logic output signal. The system also includes an output superconducting XOR-2 gate that receives the intermediate superconducting logic output signal and a third superconducting logic input signal and is configured to perform a logic XOR function based on the decision pulse on the given phase of the clock signal to provide a superconducting logic output signal.

Superconducting Isochronous Receiver System
Northrop Grumman Systems Corp.
January 31, 2023
U.S. Patent No. 11,569,976
One example includes an isochronous receiver system. The system includes a pulse receiver configured to receive an input data signal from a transmission line and to convert the input data signal to a pulse signal. The system also includes a converter system comprising a phase converter system. The phase converter system includes a plurality of pulse converters associated with a respective plurality of sampling windows across a period of an AC clock signal. At least two of the sampling windows overlap at any given phase of the AC clock signal, such that the converter system is configured to generate an output pulse signal that is phase-aligned with at least one of a plurality of sampling phases of the AC clock signal based on associating the pulse signal with at least two of the sampling windows.

Isochronous Cyclotrons Employing Magnetic Field Concentrating Or Guiding Sectors
Varian Medical Systems Particle Therapy GmbH
January 31, 2023
U.S. Patent No. 11,570,880
An isochronous cyclotron including one or more coils and a plurality of pairs of bulk superconductor sectors. The one or more coils can be configured to generate a magnetic field in the beam chamber having a magnetic flux density that increases radially from the central axis of the beam chamber, and is orientated substantially perpendicular to the median acceleration plane of the beam chamber. Each pair of bulk superconductor sectors can be disposed on opposite sides of the median acceleration plane. The plurality of pairs of bulk superconductor sectors can be configured to guide or concentrate the magnetic field to provide an axial focusing component of the magnetic field.

Quantum Error-correction In Microwave Integrated Quantum Circuits
Rigetti & Co, LLC
February 7, 2023
U.S. Patent No. 11,573,259
In a general aspect, a quantum error-correction technique includes applying a first set of two-qubit gates to qubits in a lattice cell, and applying a second, different set of two-qubit gates to the qubits in the lattice cell. The qubits in the lattice cell include data qubits and ancilla qubits, and the ancilla qubits reside between respective nearest-neighbor pairs of the data qubits. After the first and second sets of two-qubit gates have been applied, measurement outcomes of the ancilla qubits are obtained, and the parity of the measurement outcomes is determined.

3D Transmon Qubit Apparatus
Samsung Electronics Co., Ltd.
February 7, 2023
U.S. Patent No. 11,574,229
Provided is a 3D transmon qubit apparatus including a body portion, a driver, a transmon element disposed in an internal space of the body portion, a first tunable cavity module disposed in the internal space of the body, and comprising a first superconductive metal panel; and a second tunable cavity module disposed in the internal space of the body, and comprising a second superconductive metal panel, wherein the transmon element is disposed between the first superconductive metal panel and the second superconductive metal panel; wherein the first tunable cavity module and the second tunable cavity module are configured to adjust a distance between the first superconductive metal panel and the second superconductive metal panel, and wherein the driver is configured to tune a resonance frequency by adjusting a 3D cavity by adjusting the distance between the first superconductive metal panel and the second superconductive metal panel.

Microwave Integrated Quantum Circuits With Vias And Methods For Making The Same
Rigetti & Co, LLC
February 7, 2023
U.S. Patent No. 11,574,230
A quantum computing system that includes a quantum circuit device having at least one operating frequency; a first substrate having a first surface on which the quantum circuit device is disposed; a second substrate having a first surface that defines a recess of the second substrate, the first and second substrates being arranged such that the recess of the second substrate forms an enclosure that houses the quantum circuit device; and an electrically conducting layer that covers at least a portion of the recess of the second substrate.

Diffusion Barriers For Metallic Superconducting Wires
Matron Newton Inc.
February 7, 2023
U.S. Patent No. 11,574,749
n various embodiments, superconducting wires incorporate diffusion barriers composed of Ta alloys that resist internal diffusion and provide superior mechanical strength to the wires.

HTS Magnet Sections
Tokamak Energy Ltd.
February 7, 2023
U.S. Patent No. 11,575,078
A segment of a field coil, a toroidal field coil, and a method of manufacturing is provided. The segment of a field coil is for use in a superconducting electromagnet. The segment includes an assembly for carrying electrical current in a coil of a magnet. The assembly includes a pre-formed housing comprising a channel configured to retain high temperature superconductor (HTS) tape, the channel including at least one pre-formed curved section. The assembly further includes a plurality of layers of HTS tape fixed within the channel. Wherein the pre-formed curved section has a radius of curvature which is less than a total thickness of the layers of HTS tape in that section divided by twice a maximum permitted strain of the HTS tape.

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