Superconductor Week

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Intel Develops 17-qubit Superconducting Chip with Advanced Packaging

The Intel Corporation has fabricated a 17-qubit superconducting test chip for quantum computing that, according to the company, features a unique design that will achieve improved yield and performance. The chip has been delivered to QuTech, Intel's quantum research partner in the Netherlands.

The new chip is about the size of a U.S. quarter coin. Its architecture is aimed towards addressing qubit fragility and includes a scalable interconnect scheme that allows for 10 to 100 times more signals into and out of the chip as compared to wire-bonded chips.

"Unlike many companies in this space who are still limited to using wirebonding to connect their quantum computing chips to the outside world, Intel has developed a more scalable packaging architecture that provides orders of magnitude improved connectivity and better electrical and thermo-mechanical performance," commented an Intel spokesperson. "This is built upon the state-of-the-art packaging techniques used in our transistor process."

Intel Focused on Chip System Design

Intel's processes, materials and designs enable the packaging to scale for quantum integrated circuits, which are much larger than conventional silicon chips. The chip's new architecture also reportedly improves reliability, thermal performance, and reduced RF interference between qubits. It was developed by Intel's Components Research (CR) Group in Oregon and Assembly Test and Technology Development (ATTD) team in Arizona.

"With this test chip, we will focus on connecting, controlling, and measuring multiple, entangled qubits towards an error correction scheme and a logical qubit," said Professor Leo DiCarlo of QuTech. "This work will allow us to uncover new insights into quantum computing that will shape the next stage of development."

In past comments to the press, Intel management has noted that the company is more focused on engineering the system design of the chip rather than increasing the number of qubits. This means that the company is allocating more resources to research on the interconnects that will link qubits together on a device and across multiple devices. One key goal is to simplify the electronics by reducing the number of connections between qubits. Intel also aims to raise the system operating temperature to 4 K so that it can be cooled using liquid hydrogen.

QuTech Collaboration Established in 2015

QuTech is an advanced research center for quantum computing and the quantum internet that was established jointly by the Delft University of Technology (TU Delft) and the Netherlands Organization for Applied Scientific Research (TNO). The collaboration between Intel and QuTech began in 2015 with the objective of accelerating advancements in quantum computing, including expediting the time from design and fabrication to testing.

The company initially committed $50 million and engineering resources to the alliance. Over the past two years, Intel has been fabricating new qubit test chips on a regular basis which the company sends to QuTech for testing.

49-qubit Test Chip Under Development

"We started our quantum computing research effort in 2015 and have achieved many milestones since that time," the Intel spokesperson noted. "Prior to delivery of the 17-qubit test chip, we had sent many test chips of various types including several revisions of a 7-qubit test chip. We expect to deliver a 49-qubit test chip by the end of the year."

Intel is not confining its research to superconductor technology. The company and QuTech are also exploring spin qubits in silicon, which are similar in design and fabrication to the advanced CMOS transistors found in Intel's microprocessors. Last year, the partners reported that they are now able to layer the ultra-pure silicon needed for a quantum computer onto the standard wafers used in chip factories. ❍

NFRI Improves Plasma Stability in KSTAR Fusion Device

Researchers with the Korean National Fusion Research Institute (NFRI), General Atomics, and the DOE's Princeton Plasma Physics Lab (PPPL) have sharply improved the stability of the elongated plasma in the Korea Superconducting

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Tokamak Advanced Research (KSTAR) device, setting an example for how to address similar issues in other superconducting devices such as ITER.

The successful control method caps years of efforts to control the vertical instability of the plasma in magnetic confinement fusion (MCF) reactors. Vertical instability allows the plasma to bounce up and down within the 11-foot-high vacuum vessel. The work received financial support from the DOE Office of Science.

"We extended the plasma height by improving the vertical stability control at maximum elongation, [which describes the] ratio of the semi-major radius to the minor radius of an elliptically shaped plasma, by up to 2.16," said KSTAR's Sang-hee Hahn. "[That figure is] beyond the designed maximum of 2.

"The result is that the allowed plasma volume increased by 20 to 25% compared to the volumes typically achieved over the previous three years. We have not resolved every issue relevant to dealing with the superconducting tokamaks' plasma control. However, we have experimentally confirmed that a more elaborate control method is able to minimize the practical issues [that arise] when we use a mix of fast copper and slow superconducting coils as actuators for magnetic control, as is the case with KSTAR and ITER."

Engineering Constraints Limit Reaction Time of SC Coils

A major challenge facing the development of fusion energy is maintaining the ultra-hot plasma that fuels fusion reactions in a steady-state, or sustainable, form using superconducting magnetic coils to avoid the tremendous power requirement of copper coils. While superconductors can allow a fusion reactor to operate indefinitely, controlling the plasma with superconductors presents a challenge because engineering constraints limit how quickly such magnetic coils can adjust when compared to copper coils that do not have the same constraints.

The slower response time of these superconducting coils creates the problem. The slower pace makes it difficult to operate a stable discharge with the large plasma volume or extend the vertical height required for producing fusion power.

"The superconducting poloidal field (PF) coils are installed at a relatively distant place from the plasma position," said Hahn. "The presence of various mechanical structures between the coils and plasmas such as the thermal shield, a thick vacuum vessel, and the superconducting toroidal field (TF) coils around the vacuum vessel, means that the PF coils usually have larger inductances than the copper ones used for the same purpose.

"The distance between the PF coils and the plasma complicates the control design because the plasma response is influenced by the flux changes of each individual coil. The reaction time of the superconducting coil is proportional to its self-inductance and is thus slower than the copper one if provided the same voltage as the power supply.

"In KSTAR, the most effective coils for providing the required vertical stabilization are the copper in-vessel coils (IVCs) with a corner frequency of ~110 Hz, but the slower PF coils can also respond to any vertical movement of the plasma through low-frequency shape control.

"The situation usually leads to unmanageable responses from the IVC due to phase delay by the slower PF coils. The new control design tries to decouple the fast vertical stabilization feedback control loop from the slow shape control in the frequency domain, and ensures that the slower PF coils only respond to the DC few-Hz movement of control points."

Exploration of the issue of plasma control in a superconducting device is particularly helpful for ITER, the international fusion experiment under construction in France that will be operational in 2025. KSTAR's superconductors are made of Nb_3Sn, the same conductor that is planned for use in

ITER.

Improved Electronics Key to Plasma Control

Key to the new plasma control method are modified electronics for sensors that detect the magnetic field of the plasma and the plasma's motion and position. The modified sensors, designed by scientists at Princeton Plasma Physics Lab (PPPL), provide a better signal-to-noise ratio that can allow for more accurate feedback on the vertical position of the plasma. The feedback uses an IVC to push back on the changes in the vertical position and prevent termination of the plasma.

In addition to the sensor improvements, General Atomics developed a control system that distinguishes between fast and slow changes in the sensor signals and directs different coils to respond to the plasma movement on different time scales. The end result is a control system that responds effectively to movements of the plasma, enabling operation with taller plasmas that exceed the KSTAR design requirements.

"The improved sensors enhance the feedback loop relevant to the copper IVC," added Hahn. "We plan to use the new plasma control method to enhance KSTAR operations by developing more stable discharges and extending KSTAR's operational space. KSTAR operations will resume in the second half of 2018."

KSTAR Operational Since 2009

Construction on KSTAR began in December 1995 and was completed in August 2007 at a cost $306 million (see *Superconductor Week*, Vol 21, No 17). It was the first fusion research device to feature a fully superconducting magnet system with Nb_3Sn central solenoid, TF, and PF coils.

The first experiment was conducted in 2009. KSTAR achieved a number of milestones within two years of opening, including operation at full TF at 3.5 T and with electron cyclotron heating (ECH) pre-ionization at the fundamental harmonic frequency (see *Superconductor Week*, Vol 23, No 20). Five years ago, KSTAR became one of the first tokamaks to achieve the full suppression of edge-localized modes, which can cause excessive erosion of plasma-facing components (see *Superconductor Week*, Vol 26, No 1).

Earlier this year, NFRI announced that KSTAR achieved a world record of 70 seconds in high-performance plasma operation (see *Superconductor Week*, Vol 31, No 2). The figure exceeded the 55-second duration reached by KSTAR for high temperature plasma in 2015. ❍

IBM Launching 20- and 50-qubit Quantum Processors

IBM has announced two quantum processor upgrades for its IBM Q early-access commercial systems. Its clients will have online access to the computing power of the first of these by the end of 2017, with a series of planned upgrades planned during 2018. The company is also seeking to expand the use of its quantum computing systems through the establishment of the IBM Q Network and the Quantum Information Software Kit (QISKit) project.

The first new system has a 20-qubit processor made of niobium, silicon, and aluminium, which features improvements in superconducting qubit design, connectivity, and packaging. Coherence times will have an average value of 90 µs, allowing for high-fidelity quantum operations. That is twice the coherence of the company's currently available 5- and 16-qubit systems, which averaged 50 and 47 µs respectively.

The company has also built and measured an operational prototype 50-qubit processor with similar performance metrics. The new processor expands on the 20-qubit architecture with a 10 × 5 qubit array, and will be made available in the next generation IBM Q systems. Over the coming year, IBM Q scientists plan to continue working to improve these devices, including the quality of qubits, circuit connectivity, and error rates of operations in order to increase the depth for running quantum algorithms.

Improving Quantum Volume a Primary Goal

IBM first launched a working 5-qubit quantum computer online for anyone to freely access in May 2016 (see *Superconductor Week*, Vol, 30, No 9). The company made its 16-qubit machine available to the public earlier this year. Its system is based on superconducting transmon qubits, which store quantum information in terms of the presence or absence of Cooper pairs of electrons.

"IBM's goal is to improve and increase quantum volume, a metric that encompasses more than just additional qubits," an IBM Research source said. "It accounts for the number and quality of qubits, circuit connectivity, and error rates of operations. In practical devices, the effective error rate depends on the accuracy of each operation it takes to solve a particular problem, as well as how the processor performs these operations."

Through the IBM Q Experience, which enables registered users to connect to IBM's quantum processors through the IBM cloud, over 60,000 users have run over 1.7 million quantum experiments on their quantum computers, generating over 35 third-party research publications. Users have registered from over 1500 universities, 300 high schools, and 300 private institutions worldwide.

IBM Q Network Established

IBM has also launched the IBM Q Network, a collaboration of Fortune 500 companies, academic institutions, and national research labs working directly with the company to advance quantum computing. Through the network IBM will seek to nurture a growing quantum computing ecosystem based on its open source quantum software and developer tools. Initial members include JPMorgan Chase, Daimler AG, Samsung, JSR Corporation, Barclays, Hitachi Metals, Honda, Nagase, Keio University, Oak Ridge National Lab, Oxford University, and the University of Melbourne.

The organizations will have access to IBM's most advanced and scalable universal quantum computing systems, starting with a 20-qubit IBM Q system. They will work directly with IBM to pioneer quantum computing for their respective industries by exploring a broad set of potential specific applications.

Five Regional Hubs to Provide Access to Quantum Computing

In support of the initiative IBM will establish five regional hubs to increase access to quantum systems and advance research. The planned locations are at IBM Research in New York, Keio University, Oak Ridge National Lab, Oxford University, and the University of Melbourne.

IBM is also introducing IBM Q Consulting, which is intended to bring together consultants, scientists, and industry experts to assist clients in understanding how quantum computing technology might expand their business opportunities and provide customized roadmaps to help businesses become quantum ready. IBM Q Consulting will focus initially on logistics and modeling use cases in industries such as mining, banking, life sciences, and electronics.

IBM Rolls Out Quantum Software Project

To assist users with its quantum systems, IBM earlier this year rolled out its QISKit project, an open-source software developer kit to program and run quantum computers that can be found at https://qiskit.org. Recently, the company added new functionality and visualization tools to QISKit for studying the state of the quantum system, integrating the project with its IBM Data Science Experience, a compiler that maps desired experiments onto available hardware. QISKit users currently have access to IBM's 16-qubit processor.

IBM Research has also announced a series of prizes for professors, lecturers and students who use the IBM Q Experience and QISKit in the classroom or for their research. Awards will be made available for developing open source course materials for a lecture series, building Jupyter Notebook tutorials with QISKit, contributing specific code modules to the open source QISKit software development kit, and to students who publish a scientific paper that makes use of QISKit. Details are available at https://qe-awards.mybluemix.net. ❍

IBA Announces Lower Q3 Proton Therapy Revenues

IBA reported that over the first three quarters of FY2017 revenue from its Proton Therapy and Other Accelerators division declined by 7.8%, to €175.9 million ($206.7 million) from €190.9 million ($224.3 million) during the first three quarters of FY2016. However, proton therapy revenues declined by only 2.4% despite the negative impact of slow order intake, project rescheduling, and exceptional items.

Proton Therapy and Other Accelerators orders at end of Q3 FY2017 totalled €76.7 million ($90.1 million) and consisted of two ProteusONE and one ProteusPLUS systems (three projects and four rooms in total), plus five other accelerators. The order intake also includes upgrades for €4.7 million ($5.5 million). IBA is currently implementing 25 international proton therapy installation projects.

The division's backlog was €284 million ($333.7 million) for equipment and €682 million ($801.3 million) for services. This represented a small sequential decrease from the previous quarter's backlog of €321 million ($377.2 million) for equipment and €689 million ($809.6 million) for services.

Two Proton Therapy Collaborations Established

"Our performance in Q3 continues to reflect the challenges reported at the time of our half-year results," commented IBA CEO Olivier Legrain. "However, the proton therapy market remains buoyant and demand for IBA's leading offering is high, with over five systems in the last stages of negotiation. Furthermore, collaborations announced with Elekta and Vinci Construction during the quarter give us a more competitive and attractive offering for our customers."

With Elekta, IBA will seek to develop a new functionality for proton therapy treatment in the Swedish company's treatment planning and oncology information systems as well as co-market each other's products. IBA will collaborate with Vinci Construction to offer dedicated proton therapy project design and construction support.

Earnings Guidance Unchanged

Total IBA Group revenue for Q3 FY2017 was €65.7 million ($77.2 million), 18.2% lower than the €80.3 million ($94.4 million) reported in Q3 FY2016. Over the first three quarters of the year, revenue fell by 3.6% to €217.3 million ($255.3 million) from €225.4 million ($264.8 million) in the comparable period. The company's share price rose by 9%, from €23.45 to €25.55, on the day of its Q3 FY2017 press release.

IBA reiterated the earnings guidance that it provided at the end of Q2 FY2017 based on scheduled revenue recognition in Q4 FY2017 from its backlog. FY2017 revenues are expected to grow 5 to 10%, followed by flat to mid-single digit growth in 2018 to 2019. Operating margins are expected to be in the low- to mid-single digits in 2017, and in the mid- to high-single digits in 2018 and 2019. ❍

STI's Conductus Wire Meets Customer's Specifications

Superconductor Technologies Inc. (STI) announced in its Q3 FY2017 earnings report conference call that it had attained the required specification for a key customer's application for its Conductus HTS wire. The results were confirmed through independent testing by New Zealand's Robinson Research Institute. The company has recently shipped the improved wire to several customers with near-term wire demand forecasts.

In the quarterly earnings conference call, Jeff Quiram, STI's President and CEO, said he was advised by the customer that testing Conductus would be of the highest priority. He noted that lab testing is usually a 2- to 4-week feedback loop.

Conductus Shows 40% I_c Capacity Improvement in DOE Project

Interest in Conductus wire within the industry is extremely high, Quiram noted: "Our discussions with industry leaders have never been more active. At the EUCAS conference in Geneva, customer discussions revolved around developing a plan to supply wire for their projects. We believe the current and near future initiatives being pursued underscore that potential demand for Conductus wire is greater than ever."

Quiram also provided an update on STI's contract negotiations for its project under the DOE's Next Generation Electric Machines (NGEM) program (see *Superconductor Week*, Vol 31, No 1): "At this time, we have demonstrated a 40% improvement in I_c capacity above the baseline set at the beginning of the project. Ultimately, our program objective is to produce wire that delivers 1,440 A/cm-width at 65 K and 1.5 T."

Cash on Hand will Fund Operations through Q1 FY2018

For Q3 FY2017, STI reported net revenues of $130,000, a 491% increase from Q3 FY2016 revenues of $22,000. The revenues were primarily realized from legacy wireless products. The quarterly net loss was $2.5 million compared to $2.9 million over the comparable quarter last year.

For the first three quarters of FY2017, STI reported revenues were $139,000, a 13.9% gain over $122,000 in revenues during the first three quarters of FY2016. Net loss declined to $7.7 million from $8.6 million. The company's share price rose by 11.3%, from $0.97 to $1.08, on the day of the earnings announcement.

STI held $4.6 million in cash on its balance sheet at the end of Q3 FY2017 compared to $6.4 million at the end of the previous quarter. In the earnings conference call, CFO Bill Buchanan stated that existing cash resources would be sufficient to fund planned operations through Q1 FY2018. ❍

OI Restructures Business to Drive Sales Growth

Oxford Instruments plc, (OI) has announced that aggregate revenues for its half-year through September 30, 2017 declined by 0.2% to £132.1 million ($173.3 million) compared to £132.4 million ($173.7 million) for the same period in 2016. On a constant currency basis, revenues fell by 4.5%.

OI realized an adjusted operating profit of £18.8 million ($24.7 million) compared to an adjusted operating profit of £16.4 million ($21.5 million) the previous year, a 14.6% gain. On a constant currency basis, adjusted operating profits fell by 12.2% due to the impact from lower first half microscopy revenue and longer production lead times for customised magnet and cryogenic systems. The company's share price dropped by 1.9%, from £9.70 ($12.96) to £9.52 ($12.72), on the day of the earnings announcement.

New Orders and Backlog Grow

"We introduced our Horizon Strategy in June, outlining how it will help us achieve sustainable revenue growth and margin improvement," commented OI CEO Ian Barkshire. "Horizon focuses the Group on those markets where nanotechnology will provide long-term growth drivers for our customers and where we have the opportunity to achieve or maintain market leadership.

"We have made progress in a number of areas in support of our new strategy. We have undertaken significant management of the portfolio, successfully completing the sale of Industrial Analysis in July, making us a more focused nanotechnology group."

New orders during the period grew by 6% to £148.5 million ($194.9 million) compared to £140.1 million ($183.8 million) a year ago, increasing 1.8% in constant currency. The backlog as of September 30, 2017 increased 11.8% at constant currency since year-end and is up 3.3% at constant currency on the prior half year.

OI has restructured its business operations so that divisions are more customer application and market focused rather than product focused. Benchtop NMRs, which were previously in the Industrial Products sector, and superconducting magnet systems, which were in the Nanotechnology Tools sector, are now both within the NanoScience division of the Research and Discovery sector.

Customized Magnet Orders Depress Margin

The revenues of the Research and Discovery sector fell by 13.4%, or 17.5% in constant currency, to £48 million ($63 million) from £55.4 million ($72.7 million) the previous year. The sector reported an adjusted operating profit of £4.2 million ($5.5 million), 40% lower than the £7 million ($9.2 million) realized in the comparable period. The adjusted operating margin sank to 8.8% from 12.6%.

"This sector saw an increase in orders in the period but with lower revenue and profitability due to softer financial performance from our [non-superconducting] optical microscopy products in Andor Technology and a higher proportion of longer production lead time specialist system orders from NanoScience," Group Finance Director Gavin Hill noted in the operations review of the half-year earnings report. "Strong [NanoScience] order growth was driven by government and commercial focus and associated funding into quantum technology, including quantum information processing and sensors. An increase in the proportion of customised magnet and cryogenic systems has depressed financial performance."

These factors were counterbalanced by higher demand for magnetic resonance products. OI's benchtop NMR solutions, such as the enhanced Pulsar and MQC+ systems, have driven strong order growth. ❍

CERN Completes Installation of FRESCA2 Magnet

CERN has recently completed installation of the FRESCA2 magnet, a superconducting Nb_3Sn dipole magnet with a large aperture. The magnet will be used by CERN and its partners to advance their efforts to develop superconducting magnets that will be capable of generating fields of 16 T and more for use in future colliders such as the Future Circular Collider (FCC).

The Large Hadron Collider (LHC) currently deploys superconducting magnets capable of generating fields of 8 T. These will be replaced with 12 T superconducting Nb_3Sn magnets being manufactured via the High-Luminosity LHC upgrade project (see *Superconductor Week*, Vol 25, No 24).

FRESCA2 Magnet Funded via EuCARD-2

One of the key steps in the program to develop stronger Nb3Sn magnets is the development of a test station capable of testing the Nb_3Sn cables under strong magnetic fields. In order to meet this requirement, FRESCA2 was developed as part of a collaboration between CERN and CEA-Saclay in the framework of the European EuCARD-2 program.

The EuCARD-2 program is a four-year program that began in 2013 and involved over 40 partners from 15 EU countures including CERN, CEA, the Karlsruhe Institute of Technology, the University of Geneva, the University of Twente, and Bruker HTS. The aim of the project was to develop an HTS accelerator-quality demonstrator magnet, called Feather2, able to produce a standalone field of 5 T and between 17 and 20 T when inserted into the FRESCA2 high-field magnet.

The first Feather2 magnet was built using an initial version of HTS conductor based on REBCO tapes. The magnet was tested during the summer and achieved a standalone field of over 3 T. The next magnet, based on high-performance REBCO tape, is expected to exceed the 5 T target by a significant margin, possibly approaching a field of 8 T.

At the start of August, FRESCA2 achieved its design magnetic field, generating 13.3 T at the centre of a 10-cm aperture for 4 hours in a row, a first for a magnet with such a large aperture. By comparison, the current magnets in the LHC generate fields of around 8 T at the centre of a 50-mm aperture.

Ability to Adjust Magnet Field Intensity Key for Accelerators

The precision with which the intensity of the magnetic field can be adjusted is an important feature for an accelerator. When the energy of the beams is increased, the intensity of the field that guides them must be increased gradually without sudden spikes or the beams could be lost. The fact that the LHC's magnets can be adjusted with a great degree of precision, keeping their magnetic fields stable, is what allows the beams to circulate in the machine for hours at a time.

The two Nb_3Sn coils of FRESCA2 are maintained at a temperature of 2 K. The magnet they form is much larger than an LHC magnet, measuring 1.5 m in length and 1 m in diameter. This allows the magnet's 10-cm aperture, which in turn allows it to house the Nb_3Sn cables being tested as well as sensors to observe their behaviour.

FRESCA2 will also be used to test HTS coils. The magnet is being modified so that it will be able to generate an even stronger field, at which point the station will be ready to receive samples for testing. ❍

MPSD Leads Study of SC Bismuthate BPBO

Researchers from the Max Planck Institute for the Structure and Dynamics of Matter (MPSD), Stanford University, and the University of Oxford have concluded a study of superconducting $BaPb_{1-x}Bi_xO_3$ (BPBO). BPBO is a poorly understood superconductor belonging to the bismuthate family.

The research leading to the results received funding from the European Research Council (ERC) under the EU's Seventh Framework Program. Work at Stanford University was supported by the Air Force Office of Scientific Research.

Research Part of Program to Control Ordered States in Quantum Materials

"This research is part of a wider research program, whose all-embracing goal is the deterministic control of ordered states in complex quantum materials," said Daniele Nicoletti, MPSD Researcher who co-authored the study. "This includes optimizing superconductivity at higher temperatures, possibly even at room temperature.

"Superconductivity in BPBO was first discovered in the 1970s. After the discovery of high-T_c cuprates, doped bismuthates were dubbed 'the other high-T_c superconductors.' With respect to their better-known relatives, they display several commonalities, including the presence of HTS in proximity to a charge ordered phase, but also substantial differences.

"Remarkably, unlike HTS cuprates, bismuthates are non-magnetic materials and are not characterised by strong electron correlation. The mechanism behind the superconducting pairing [in bismuthates], although not fully understood, is more likely to be lattice-mediated. For these reasons, it is very interesting to study the photo-induced response of these materials and compare it to that of cuprates."

Bismuthates have Robust CDW Phase

The bismuthate parent compound, $BaBiO_3$, has a robust charge-density-wave (CDW) phase from which superconductivity emerges via chemical substitution. Nicoletti elaborated on some of the characteristics of the BPBO sub-family of bismuthates: "The maximum T_c found in the BPBO family is 11 K, while the related compound BKBO shows a T_c of 34 K.

"[Bismuthates have been understudied relative to cuprates due to] their far lower T_c's, which make them less attractive for applications. Nonetheless, there seems to be a revival of interest in bismuthates in the past few years because of their peculiar properties. A comprehensive understanding of the physics of these materials might be of key importance for unveiling the high-T_c mechanism."

Team Establishes Coexistence of CDW, SC in BPBO

The phase diagram of BPBO encompasses the CDW order in $BaBiO_3$ (x=1) through superconductivity for intermediate compositions to bad metal behavior in $BaPbO_3$ (x=0). The researchers found evidence for the coexistence of the CDW order and superconductivity for underdoped compositions of BPBO, something that had been discussed previously but never definitively established.

"The temperature-doping phase diagram of BPBO has already been characterized in the past with different techniques," said Nicoletti. "The presence of a CDW insulating phase in the undoped parent compound $BaBiO_3$ is well established, as is its evolution into a metallic state with increasing doping, which turns it into a superconductor at low temperatures."

"What was not fully clear is up to which doping level the CDW phase extends and whether it persists for superconducting compositions, at least in the form of local fluctuations. In the underdoped compound investigated in our experiment, the T_c of 7 K was first characterized with conventional transport techniques.

"Afterwards, we used the same crystal to study the photoconductivity on optical excitation and were able to identify a response that could be uniquely attributed to the melting and successive reformation of the CDW order. We consider it a demonstration of the coexistence of superconductivity and CDW in the same compound, which was not yet fully established in BPBO."

CDW Phase Points to Commonality between Bismuthates, Cuprates

The results are timely given that CDW correlations have recently been found in some underdoped cuprate superconductors, pointing towards a commonality between some aspects of these materials. The team's measurements also put energy scales on the associated charge order.

"In general, fluctuating charge order might play a role in the mechanism behind HTS," said Nicoletti. "Our result is an additional demonstration that the presence of such charge order phases in coexistence and competition with superconductivity is most likely a commonality for many different families of HTS."

Future Research may look at Stabilizing Transient SC

Nicoletti also described the next steps in his team's research: "The field of optical control of HTS is novel. So far, we have investigated a number of different families including cuprates, organic fullerides, and recently bismuthates. One can imagine that in the future, new studies on iron-based superconductors and other families of organics will appear.

"The approach to resonantly drive lattice phonons or local molecular vibrations in the mid-infrared has been shown to be very successful for enhancing superconductivity in certain compounds, while strong-field terahertz pulses have been used to study intrinsic nonlinearities in the physics of cuprates and probe them in new ways.

"I can envision the important challenge of stabilizing light-induced superconductivity on longer time scales as a next big direction. This could possibly be done using new excitation schemes with longer driving laser pulses with the goal of probing these transient states with more conventional techniques." ❍

Ningbo, Northwest U Study SC in Iron-free Pnictides

Researchers with Ningbo University and Northwest University in China have concluded a study of superconductivity in 122-type pnictides without iron. In particular, the researchers examined iron-free pnictides with a $ThCr_2Si_2$-type or related structure due to the similarities of these structures to $BaFe_2As_2$. The research received support from the National Natural Science Foundation of China (NSFC 11704311).

Fermi Surface Measurements Help in Comparing SC Materials

"This study originated from my previous research report on $EuPt_2As_2$," said Pan Zhang, Ningbo U Researcher who co-authored the study. "Searching for new superconductors in layered structures has proven a rational route to take and the similarity in structure between iron-free 122-type pnictides and $BaFe_2As_2$ is a prerequisite [for finding similarities] between the physical properties and Fermi surface between the two.

"It is possible to draw a number of comparisons between the superconducting properties of iron-free pnictides and iron pnictides. [On the other hand] many articles, particularly articles on iron-free pnictides, mention the discrepancy between the two systems.

"Apart from basic measurements like electrical resistivity and magnetic susceptibility, experiments that are able to measure the Fermi surface properties of materials are most valuable to any comparison. The Fermi surfaces of iron pnictides determined from measurements of their Fermi surface properties are definitely different from those of iron-free pnictides. As far as [applications for iron-free 122-type pnictides are] concerned, the possibility of using them in an applied way is low because they have low T_c's and limited physical properties."

Iron-free Materials help Uncover Pairing Mechanism in 122 Iron Pnictides

The study of the superconducting properties of iron-free pnictides is useful to better understand the pairing mechanism of 122 iron pnictides. Zhang said that comparing different materials was useful when studying the pairing mechanism: "Direct study of the iron pnictides is the main method used assess their intrinsic properties.

"However, we can gather information about the pairing mechanism in pnictides by comparing their properties to those of other similar systems. This is a way to figure out what kind of pairing state the iron pnictides possess, particularly when many reports offer controversial results regarding their

Fermi surface properties."

The researchers found evidence of a fully gapped superconducting state via specific heat and thermal conductivity measurements for $BaNi_2As_2$ and $SrNi_2P_2$, and nuclear magnetic and quadrupole resonance measurements for $CaPd_2As_2$. Combined with the fact that no magnetism was observed in 122-type iron-free pnictides superconductors, the majority of evidence appears to suggest that most of these compounds are conventional electron-phonon-mediated superconductors.

"Most experimental results suggest that iron-free pnictides are conventional electron-phonon-mediated superconductors," said Zhang. "The most remarkable feature of conventional superconductors is their fully gapped state, which can be measured in various ways, for instance via specific heat, thermal conductivity, and NMR measurements.

"Different pairing states have different results. By comparing the experimental results obtained for iron-free pnictides and iron pnictides, we can establish that most iron pnictides are unconventional superconductors with a s±-wave pairing state.

"There are many other compounds [that have similar systems] that deserve to be explored and investigated. Combined with the fact that many known iron-free pnictides haven't been studied in detail, I think that the next steps will involve research into both." ❍

Team Finds TRSB in Re_6Hf

Researchers from the Indian Institute of Science Education and Research Bhopal (IISERB), the Paul Scherrer Institute, the Tata Institute of Fundamental Research, the University of Warwick, and STFC Rutherford Appleton Lab have observed time-reversal symmetry breaking (TRSB) in the unconventional superconductor Re_6Hf. Their findings suggest that studies of the Re_6X family may lead to an understanding of the physics of other unconventional superconductors.

The work is part of the IISERB project 'Time Reversal Symmetry Breaking in Non-centrosymmetric Superconductors.' The project is financially supported by the Science and Engineering Research Board, the Government of India, and the Newton Bhabha Fund.

TRSB Observed in Very Few Non-centrosymmetric Superconductors

Understanding the mechanism of superconductivity in unconventional superconductors has the potential to offer applications in the future. Unlike BCS superconductors with their inversion symmetry, in which pairing states form in either spin-singlet configurations with even parity or as spin-triplet pairs with odd parity, non-centrosymmetric superconductors with antisymmetric spin-orbit coupling exhibit significantly different properties such as TRSB.

TRSB remains an exceptionally rare phenomenon even in these types of superconductors, and researchers have concluded that only certain irreducible representations of the crystal point group permit such pairing states. To date, the only non-centrosymmetric superconductors that have been found to exhibit TRSB are $LaNiC_2$, Re_6Zr, locally non-centrosymmetric SrPtAs, and La_7Ir_3. Time-reversal symmetry has been preserved in $Ca(Ir,Pt)Si_3$, $La(Rh,Pt,Pd,Ir)Si_3$, $Mg_{10}Ir_{19}B_{16}$, Re_3W, and Mo_3Al_2C.

TRSB a Means of Finding P-wave Superconductors

"Investigation of TRSB is one of the key routes to discovering p-wave superconductors," commented IISERB Researcher Rajinder Singh. "In the Re_6X family, compounds range from 3d to 5d and most of them are superconductors. This gives control to antisymmetric spin-orbital coupling, which is believed to play an important role in TRSB."

The binary transition-metal compound Re_6Hf is a bulk superconductor with a T_c of 5.98 ± 0.02 K and a superconducting state that appears to be predominantly s-wave with enhanced electron-phonon coupling. The research team used Muon spin rotation and relaxation to observe a tiny magnetic signal providing evidence of TRSB in the material's superconducting state. The signal was similar to one found in superconducting Re_6Zr, indicating that Re_6X is a family of unconventional superconducting materials in which the effect of spin-orbit coupling on the superconducting state might be investigated.

"To date, only Re_6Zr and Re_6Hf have been investigated," said Singh. "We are working on few more compounds in this series. We are using these findings to understand the mechanism of TRSB and designing new p-wave superconductors." ❍

SISSA-led Team Explains Brief HTS in Fullerides

Researchers from the International School for Advanced Studies in Trieste (SISSA), the Catholic University of Brescia, and the French National Center for Scientific Research (CNRS) have proposed a new mechanism as to why the alkali fulleride A_3C_{60} briefly became superconducting at high temperatures when struck by a laser pulse (10.1038/ nphys4288). They propose that the superconducting state is triggered by a high-energy molecular excitation caused by the laser pulse.

Understanding and stabilizing the phenomenon offers the prospect of developing future electronic devices whose properties could be altered with the use of light. The research received financial support from the EU under ERC FIRSTORM (Modeling first-order Mott transitions), ERC MODPHYSFRICT (Modeling the Physics of Nano-Friction), and ERC Q-MAC (Frontiers in Quantum Materials' Control).

"In the past we have worked extensively on fullerides," commented SISSA Professor Michele Fabrizio. "We were among the few to claim that these compounds are as correlated as HTS cuprates. We also anticipated the proximity of the superconducting phase to a Mott insulating one before this was actually observed in over-expanded Cs_3C_{60}."

K_3C_{60} First Fullerene Found to be Superconducting

Fullerenes are carbon molecules in the form of a hollow sphere, ellipsoid, tube, and many other shapes. They are similar in structure to graphite, which is composed of stacked sheets of linked hexagonal rings, but may also contain pentagonal or heptagonal rings.

The first fullerene molecule, Buckminsterfullerene or C_{60}, was discovered in 1985. In 1991 superconductivity was first observed in a fullerene-based material, potassium-doped fulleride, K_3C_{60}.

A fulleride is a fullerene doped with a metal atom. Alkali-doped fullerides are molecular solids where each lattice site is occupied by a C60 molecule. They offer additional degrees of freedom to control.

Superconductivity at 200 K Briefly Observed

K_3C_{60} has been found to be a superconductor with a T_c of 20 K. In 2016, a research team at the Max Planck Institute for the Structure and Dynamics of Matter observed that, after irradiation by an intense femtosecond infrared pulse between 80 and 200 meV, K_3C_{60} showed a transient regime lasting a few picoseconds (see *Superconductor Week*, Vol 30, No 3).

The fulleride's properties resembled those of a superconductor in this brief state, which occurred at temperatures up to 200 K, ten times higher than the equilibrium T_c. Theorists have attempted to explain this transition, and have mainly assumed that TO phonon infrared spectroscopy absorption acts as the critical ingredient for increasing electron pairing efficiency.

Exciton Receives Heat while Metallic Component Cools

The SISSA-led team proposed a different mechanism. K_3C_{60} is a strongly correlated material in which purely molecular features coexist alongside metallic properties. The transient superconducting state is observed in a broad pumping frequency range that coincides with a high-energy molecular excitation, a super-exciton.

"The laser pulse creates the triplet excitons," Fabrizio noted. "However, the process requires a concurrent transfer of entropy to the excitons from the low-energy metallic component, which then cools.

"Our theory is based on the prediction that the absorption peak is due to a spin-triplet exciton. This hypothesis could be tested, e.g. in the antiferromagnetic Mott insulating phase of Cs_3C_{60} at ambient pressure. Should a similar low-frequency absorption peak also be observed in this insulator with a 1 eV charge gap, it would strongly support our theory." ❍

SLAC Finds Fluctuating Electron Stripes in Cuprates

Researchers from the SLAC National Accelerator Lab and Stanford University have demonstrated through computer simulations that cuprates contain fluctuating stripes of electron charge and spin at higher temperatures than had previously been observed (10.1126/science.aak9546). Their findings may prove useful to experimentalists and contribute to computational techniques that advance research into cuprate superconductivity. The work received financial support from the U.S. DOE, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering.

"A key difficulty in developing a theory of HTS lies in the complexity of the cuprate phase diagra," commented Stanford Researcher Edwin Huang. "Any theory of superconductivity in cuprates must also account for the various other phases in the vicinity of superconductivity. Stripe phases, or generically uniaxial spin and/or charge ordering, are particularly prominent players in the phase diagram as they overlap and sometimes even compete with superconductivity.

"In the cuprates, although stripes are sometimes seen to compete with superconductivity, there have been many proposals linking fluctuating stripes to the mechanism of superconductivity. [Understanding the relationship between stripes and superconductivity is important] for developing a theory of HTS, finding or designing higher-T_c superconductors, and is of general importance to understanding the various phases of the cuprate phase diagram.

"It should be noted that stripes are also present in several other non-superconducting transition metal oxides. Clarifying the role of stripes in these strongly correlated electron systems is important to understanding why specifically the cuprates have such high superconducting T_c's."

Subtle and Fluctuating Electron Stripes at Higher Temperatures

Electron stripes are zones where electrons either pile up, creating bands of negative charge, or align their spins to create bands of magnetism. They were previously known to exist in cuprate superconductors at temperatures near absolute zero where the stripes showed little movement, leaving unclear their role in superconductivity.

"In our study, we establish the presence of fluctuating stripes in a minimal model of the cuprate's electronic physics," Huang said. "By calculating dynamical response functions for the model, we can make direct comparisons to inelastic neutron and x-ray scattering experiments on cuprates. The similarities we find to these existing experimental data support the longstanding, and controversial, hypothesis of fluctuating stripes in the cuprates."

The SLAC/Stanford team computationally demonstrated that these stripes also exist at higher temperatures but are subtle and fluctuate in a way that could only be discovered through precise numerical computer simulations. They modeled electron behavior and interactions in a cuprate copper oxide layer on Stanford's Sherlock supercomputer cluster at SLAC and at the DOE's National Energy Research Scientific Computing Center in Berkeley.

Stripes Appear to be a Trait Universal to Cuprates

This is the first time that the behavior of cuprates has been simulated at higher temperatures with a realistic model that covers a large enough area of the material to see fluctuating stripes. Previous studies had focused on the behavior of smaller areas that were not large enough to see stripes emerge. The simulations revealed that stripes emerge at temperatures up to 600°C and in a wide range of doping conditions, and the stripes appear to be a universal trait in HTS cuprates.

"We are currently collaborating closely with experimentalists who perform x-ray scattering experiments on cuprates," Huang noted. "While these projects do not directly involve stripes, we are performing the same type of simulations on the same model. Comparing against the experimental data provides confirmation that our calculations accurately reflect the behavior of the cuprates.

"There are many possible directions for exploration via numerical simulations. One question we want to address is the origin of the differences in cuprate compounds of the stripe ordering wave vectors' doping dependence. These differences have not been captured to date via numerical simulations." ❍

Superconductivity Roundup

Events & Opportunities from Around the Industry

SW **Volkswagen** has announced that it **will use Google's universal quantum computer** to research new battery technologies for its upcoming electric vehicles, make its self-driving systems smarter, and improve traffic flow in cities. Volkswagen was the first carmaker to adopt quantum computers. Earlier this year, it announced its first successful project to significantly improve travel times for 10,000 taxis in Beijing using a D-Wave quantum annealing computer.

The company now seems set to try Google's potentially more advanced universal quantum computer. D-Wave builds a more specialized type of quantum computer, so Volkswagen should be able to develop a broader array of projects that take advantage of quantum effects with Google's more general purpose quantum computer.

sw **Market Reports World** has released the "**Superconducting Magnetic Energy Storage Market Report**" in which it forecasts that the SMES industry will grow at a steady CAGR of 6.37% for the period 2017 to 2021. The report covers key vendors including AMSC, Bruker, Southwire, and Sumitomo Electric Industries.

sw Cryogenic cooling company **ICE Oxford Ltd.** has received the **Hysics Award for Outstanding Innovative Work** from the **Institute of Physics** (IOP) for the development of the 1.0 Kelvin Cooling Power Cryogenic System at the Business Innovation Awards 2017. ICE Oxford's cooling system allows quantum computers to run at temperatures close to 0 K. The Hysics Award was one of five awards presented by the IOP at the Business Innovation Awards to businesses that have built success on the application of physics to increase turnover, profitability, and jobs.

sw **D-Wave Systems Inc.** has announced **upgrades** to its superconducting **D-Wave 2000Q** quantum computer that will be implemented in early 2018. The D-Wave 2000Q will be upgraded to include reverse annealing and virtual graphs, features expected to give users increased control of the quantum processing unit. Reverse annealing allows users to specify a problem they wish to solve along with a predicted solution in order to narrow the search space for the computation.

The predicted solution may be a result of a previous quantum or classical computation, or an educated guess. Using reverse annealing, D-Wave researchers observed a 150-fold speedup over the current D-Wave 2000Q system.

D-Wave's virtual graphs feature improves the accuracy of the upgraded system by allowing control over the interaction of groups of qubits to model a node or link in a complex graph. The new feature has improved success rates by five times over earlier D-Wave 2000Q systems for common hard optimization problems and machine learning models.

sw **Mevion Medical Systems** has received **CE Marking clearance** for its superconducting **MEVION S250i Proton Therapy System.** CE Marking permits clinical use of the system within the EU and any country that recognizes the CE Mark.

European CE Marking is the first regulatory clearance for the MEVION S250i system. Mevion submitted for U.S. FDA 510(k) clearance in September.

The first European MEVION S250i proton therapy system installation will be completed in 2018 at the Zuid-Oost Nederland Protonen Therapie Centrum (ZON PTC) at the Maastro Clinic in Maastricht, the Netherlands. The core technology of Mevion's S250 Series is a gantry-mounted superconducting synchrocyclotron.

sw **Quantum Circuits Inc.** (QCI), a startup founded by Yale University researchers, has **raised $18 million in venture funding** to build and sell quantum computers. QCI will focus on building a modular quantum computer that can be reconfigured and reprogrammed, with initial applications to address drug design for biotech, improved processes for industrial chemicals, financial technology, machine learning, and energy.

Yale researchers have pioneered the field of quantum computing with superconducting circuits, introducing the transmon qubit and techniques for distributing quantum information on wires, as well as developing the first quantum algorithms and quantum error correction in integrated circuits. QCI is developing quantum computers based on a proprietary approach for error-correcting quantum bits that is hardware-efficient and requires significantly less redundancy.

"No team has done more to pioneer the superconducting approach to qubits than the QCI co-founders and their collaborators at Yale, who are responsible for a majority of the breakthroughs in solid-state quantum computing in the past decade," said Isaac Chuang, Professor at MIT and a member of QCI's advisory board. "Now QCI is putting together the multidisciplinary team that can deliver a full-stack solution for useful quantum computing."

The new funding, led by venture capital firms Canaan and Sequoia Capital, will allow QCI to combine its experience in quantum physics with the electrical, mechanical, and systems engineers needed for the scaling of quantum computers, as well as the software designers and programmers needed to develop algorithms and applications. Tribeca Venture Partners, Osage University Partners, and Fitzgate Ventures also participated in the financing.

QCI was founded in 2015. The group has produced many scientific firsts, including the development of a quantum bus for entangling qubits with wires and the first implementation of quantum algorithms and error-correction with a solid-state device.

SW **Researchers and Markets** has issued a report entitled "**Superconductors: Global Markets to 2022**" in which it forecasts that the global market for superconductivity applications will reach $8.8 billion by 2022 from $6.1 billion in 2017, a CAGR of 7.5%. The report projects that the market for superconducting magnets will grow from $6 billion in 2017 to $7.1 billion in 2022, a CAGR of 3.2%. The electrical equipment application segment of the global superconductivity technologies market is projected to grow from $66.8 million in 2017 to $1.5 billion in 2022, a CAGR of 86.2%.

SW **Researchers** with Ecole Polytechnique Federale de Lausanne (EPFL), the Paul Scherrer Institut, Carnegie Mellon University in Qatar, the University of Geneva, University College London, Centro Brasileiro de Pesquisas Fisicas in Rio de Janeiro, the Institute for Theoretical Physics in Vienna, the University of Cambridge, Nanyang Technological University, Forschungszentrum Julich, Institut Laue-Langevin in Grenoble, Universite Pierre et Marie Curie, and the Russian Academy of Sciences **have observed a quantum interaction between a group of four entangled electrons** in superconducting $SrCu_2(BO_3)_2$ crystals (10.1038/nphys4190). Prior to the observation the existence of such an interaction was purely theoretical.

A state of four entangled electrons was predicted in 1981 by physicists B. Sriram Shantry and Bill Sutherland. Shastry and Sutherland made a number of predictions describing phase changes in the superconductive material, and until now we didn't know which would be correct.

One possibility was that the electrons' spins would entangle them into groups of four rather than pairs, a condition called a plaquette singlet. Such a plaquette singlet is exactly what the researchers observed in the recent study at a pressure of around 21,500 atm.

SW **Researchers** with the DOE's Ames Lab, Iowa State University, the Berlin Helmholtz Center for Materials and Energy, and Oak Ridge National Lab **have discovered and described the existence of a unique disordered electron spin state** in a metal that may provide a pathway to finding and studying frustrated magnets (10.1103/PhysRevLett.119.147201). Condensed matter physicists use the term frustrated to describe a kind of magnet in which the spins fail to align into stable magnetic order.

In perfectly frustrated magnets called spin liquids, the disordered magnetism of these materials persists even at very low temperatures, and their unique properties are of interest in the development of quantum computing and HTS. The materials investigated to search for a perfectly frustrated magnetic state are typically insulators.

However, Ames Lab researchers were able to define a perfectly frustrated state in a metallic material, $CaCo_{1.86}As_2$. The discovery of this nearly perfectly frustrated metal provides a new avenue for tinkering with the magnetic interactions to achieve perfect frustration.

Superconductor Week

Commercialization · Markets · Products
Business Developments · R&D · Cryogenics

~Insert~

December 25, 2017 Vol. 31, No. 11

Superconductivity Stock Index

Company Name	Symbol	Prices ending 30-Dec-2016	Prices ending 30-Nov-2017	Percentage change
American Superconductor	AMSC	7.37	3.33	-55%
Oxford Instruments	OXIG.L	9.04*	11.95*	32%
Superconductor Technologies	SCON	1.23	1.04	-15%
Bruker Corporation	BRKR	21.18	35.18	66%
Furukawa Electric	5801	30.38**	52.81**	74%
Ion Beam Application	IBAB.BR	43.82***	28.99***	-34%
Superconductor Index (12/31/14 = 100)		100.00	145.58	46%
Standard and Poor's 500		2,238.83	2,647.58	15%

The Superconductivity Stock Index is a market value index as is the S&P500. It is generated by Peregrine Communications. The year-to-date percentage change is based upon the change in market value of the companies in the index. Market value is determined by the share price times the number of shares outstanding at the end of the measured period.

* Figures are derived from closing rates on the London Stock Exchange, converted from UK Pounds to U.S. Dollars
** Figures are derived from closing rates on the Tokyo Stock Exchange, converted from Japanese Yen to U.S. Dollars
*** Figures are derived from closing rates on the Brussels Stock Exchange, converted from Euros to U.S. Dollars

U.S. Superconductivity Patents

SC Magnet, MRI Apparatus, and NMR Apparatus
Hitachi, Ltd.
July 11, 2017
U.S. Patent No. 9704630
A SC magnet allows the temperature of the permanent current switch to be quickly lowered and the excitation time of the SC magnet to be shortened, an MRI apparatus and an NMR apparatus having the SC magnet. A SC magnet structure has a SC coil that is connected to a second stage of a refrigerating unit through a low-temperature-side highly thermal conductor and a permanent current switch covered by a highly thermal conductor is connected to a second stage of the refrigerating unit through a heat insulator and a low-temperature-side highly thermal conductor. Gas is supplied from a gas bottle disposed outside a vacuum vessel to a condensed in a thermal shield. In addition, a first pipe supplies condensate liquid to a liquid storage chamber. The liquid storage chamber is disposed at an upper portion of the permanent current switch. A check valve is connected to the first pipe.

Shorting Straps for SC Qubits
International Business Machines Corporation
July 11, 2017
U.S. Patent No. 9705063
A first electrode paddle and a second electrode paddle are on a substrate. The first and second electrode paddles oppose one another. A sacrificial shorting strap is formed on the substrate. The sacrificial shorting strap connects the first electrode paddle and the second electrode paddle. The tunnel junction is formed connecting the first electrode paddle and the second electrode paddle, after forming the sacrificial shorting strap. The substrate is mounted on a portion of a quantum cavity. The portion of the quantum cavity is placed in a vacuum chamber. The sacrificial shorting strap is etched away in the vacuum chamber while the substrate is mounted to the portion of the quantum

cavity, such that the sacrificial shorting strap no longer connects the first and second electrode paddles. The tunnel junction has been protected from electrostatic discharge by the sacrificial shorting strap.

MRI using SC Array Antenna
Kabushiki Kaisha Toshiba
July 18, 2017
U.S. Patent No. 9709646
A MRI apparatus includes a housing, a static magnet field source having a SC coil or a permanent magnet, and a SC array antenna which are provided inside of the housing. The SC array antenna includes an A/D conversion element configured to convert a received analog signal into a digital signal.

Automated State Machine Extraction for RSFQ Circuits
Stellenbosch University
July 18, 2017
U.S. Patent No. 9710586
An alphanumeric representation typically specifies circuit components including inductive elements, their interconnectivity and input and output nodes. The method according to the invention comprising the steps of simulating the circuit in a suitable software environment utilizing the alphanumeric representation; identifying inductive loops in the circuit; identifying inductive loops in the circuit capable of storing one or more magnetic fluxons and discarding all others; and extracting the state machine representation, using only the inductive loops in the circuit capable of storing magnetic fluxons.

Quantum Processor
D-Wave Systems Inc.
July 18, 2017
U.S. Patent No. 9710758
In a quantum processor some couplers couple a given qubit to a nearest neighbor qubit, other couplers couple to next-nearest neighbor qubits. Couplers may include half-couplers, to selectively provide communicative coupling between a given qubit and other qubits, which may or may not be nearest or even next-nearest-neighbors. Tunable couplers selective mediate communicative coupling. A control system may impose a connectivity on a quantum processor, different than an "as designed" or "as manufactured" physical connectivity. Imposition may be via a digital processor processing a working or updated working graph, to map or embed a problem graph. A set of exclude qubits may be created from a comparison of hardware and working graphs. An annealing schedule may adjust a respective normalized inductance of one or more qubits.

Magnets for Hadron Therapy Gantries
Massachusetts Institute Of Technology
July 18, 2017
U.S. Patent No. 9711254
Toroidal SC magnets can be used as lightweight rotating bending magnets in hadron therapy gantries. The toroidal bending magnets are self-shielded and do not require ferromagnetic material for field modification or shielding, decreasing both the magnet system weight, as well as overall gantry weight. Achromatic magnet can be made by combining two of these bending magnets. The simple geometry may allow the use of higher fields, making it attractive for carbon, as well as proton.

Compound SC Wire and Method for Manufacturing
Tohoku Techno Arch Co., Ltd.
July 18, 2017
U.S. Patent No. 9711262
A compound SC wire includes a reinforcement portion and a compound SC. In the reinforcement portion, an assembly of plural reinforcement elements are disposed. The reinforcement elements each include plural reinforcement filaments disposed in a stabilizer, and a stabilizing layer at the outer periphery thereof. The reinforcement filaments each mainly contain one or more metals selected from the group consisting of Nb, Ta, V, W, Mo, Fe, and Hf, an alloy consisting of two or more metals selected from the aforementioned group, or an alloy consisting of copper and one or more metals selected from the aforementioned group.

Support Structure for Cylindrical SC Coil
Siemens Healthcare Limited
July 18, 2017
U.S. Patent No. 9711267
An arrangement for supporting a cylindrical SC coil

structure has recesses in an axial end-surface of the coil structure, and support brackets that individually horizontally protrude into the recesses, such that a vertical loading on the support brackets bears the weight of the coil structure. Opposite ends of the support brackets engage a support member, which supports the support brackets engaged therein, thereby also bearing the weight of the coil structure.

Sample Transportation Apparatus in a SC Magnet
Academia Sinica
July 4, 2017
U.S. Patent No. 9696391
A precision high-speed shuttle device for transporting samples between different positions of a SC magnet with different magnetic field strength is provided. The sample equilibrated at the center of the magnet, where the magnetic field is the highest and homogeneous, is shuttled to a higher position above, where the fringe field is lower, for a defined period of time and shuttled back to the center for detection. By shuttling the sample to different positions in the magnet in different experiments one can obtain a field-dependent profile of particular physical parameters. The position and timing of the sample are precisely under the experimental controlled. In this way various magnetic field-dependent NMR experiments can be conducted in a single high-field NMR spectrometer.

Incorporating Arrays of Josephson Junctions
International Business Machines Corporation
July 4, 2017
U.S. Patent No. 9697473
A Josephson parametric converter is provided. The Josephson parametric converter includes a multi-Josephson junction ring modulator having a first, a second, a third, and a fourth node and a first, a second, a third, and a fourth array of N Josephson junctions arranged in a ring configuration with the nodes inter-dispersed between the arrays. The first array is between the first and second nodes, the second array is between the second and third nodes, the third array is between the third and fourth nodes, and the fourth array is between the fourth and first nodes. N is an integer having a value greater than one. The Josephson parametric converter further includes a first and a second resonator formed from lumped-element capacitors that shunt the multi-Josephson junction ring modulator and respectively enable a first and a second mode of the Josephson parametric converter.

Oxide SC Wire
Fujikura Ltd.
July 4, 2017
U.S. Patent No. 9697930
An oxide SC wire includes: a tape-shaped oxide SC laminate that is formed by providing an intermediate layer on a front surface side of a metal tape-shaped substrate, providing an oxide SC layer on the intermediate layer, and providing a protective layer on the oxide SC layer; and a coating member that includes a metal tape and a low melting point metal layer, in which the metal tape has a wider width than that of the oxide SC laminate and covers the protective layer surface of the oxide SC laminate, both side surfaces of the oxide SC laminate, and both end portions of a substrate back surface side in a width direction thereof, and both end portions of the metal tape in a width direction thereof are provided to cover both the end portions of the substrate back surface.

SC Coil Device
Kabushiki Kaisha Toshiba
July 4, 2017
U.S. Patent No. 9697939
According to an embodiment, a SC coil device includes a non-coplanar three-dimensional SC saddle type coil including a wound SC wire. The SC saddle type coil includes: longitudinal portions extending along a longitudinal direction of a magnetic field generation area; crossing portions extending along an edge line of a cross section perpendicular to the longitudinal direction of the magnetic field generation area; and bent portions connecting the longitudinal portions and the crossing portions. The crossing portions are linear in shape when seen in the longitudinal direction.