Superconductor Week
Commercialization · Markets · Products
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Hinetics CTO Receives Patent for Superconducting Machine

The U.S. Patent and Trademark Office has awarded a patent for a very high power density superconducting machine to Kiruba Haran, associate professor at the University of Illinois and Chief Technology Officer at Hinetics, a technology start-up based in Champaign, Illinois. The machine would significantly increase the air-gap magnetic flux density as compared to traditional machines.

"The air gap flux density is the strength of the magnetic field in the air gap of an electric machine," Haran commented. "It is a fundamental design parameter and relates directly to machine power density.

"Conventional machines operate with air gap flux densities of about 1 T. We are looking to increase this by up to ten times."

Superconducting Coils Replace Ferromagnetic Steel

The machine would achieves this benchmark by eliminating the ferromagnetic steel traditionally employed to carry and shield magnetic flux. Instead, an arrangement of superconducting main coils and a set of compensating coils similar to those employed on actively shielded MRI magnet designs, are used to cancel out the field outside the machine.

"Eliminating heavy ferromagnetic steel from the magnetic circuit leads to significantly lower weight," Haran said. "Higher operating fields are also possible since we are no longer limited by the saturation of ferromagnetic material, further increasing power density."

According to a 2016 study co-authored by Haran (DOI: 10.1109/ TASC.2016.2519409), a 17% increase in superconductor usage would reduce the radius of a 10 MW motor by 35%. The weight of the machine would be reduced even further, since much lighter weight superconducting coils would replace much heavier metal

Machine Suitable for Wind Turbines and Ship Propulsion

Hinetics was founded in 2017 with the objective of developing high frequency, high field, air-core machine technology to greatly increase power density and efficiency in electric power generation and electric propulsion applications. The company is pursuing the development of its air core technology in both superconducting and permanent magnet machines,

Potential applications for a lightweight, high power density superconducting machine include wind turbines and ship propulsion, both of which would benefit from a lighter weight energy source that does not reduce output. The technology could also cut the installation and operation costs of wind turbines, thereby increasing the attractiveness of wind as an alternative energy source.

Haran noted that Hinetics has so far carried out component tests on high field Nb_3Sn coil and air-core armature winding: "Our initial work has been with Nb_3Sn, because of cost challenges with REBCO for wind turbines. But if REBCO costs come down in the future, that could be utilized with the same machine architecture with a simplified cooling system."

NSF SBIR Phase I Project Completed

In 2018, Hinetics was awarded a $219,444 National Science Foundation (NSF) Small Business Innovation Research (SBIR) Phase I grant to conduct research and development work on actively shielded generators for large wind turbines. More recently, the company was selected by NASA for a Phase II SBIR grant for a permanent magnet motor for hybrid-electric airplanes. Although the latter is non-superconducting, it is based on air-core technology, so some developments may carry over to the superconducting motor as well.

"We recently completed the NSF SBIR Phase I, and confirmed the projected benefits with detailed computer modelling and analysis and some sub-scale component tests," Haran said. "We are now in discussions with potential partners for continued development. The next step is to reduce risk with sub-system tests on the cryogenic components, although nothing is yet firm on this front." ❍

Epoch Wires Receives Funding for MgB_2 Machine for Aviation

The Cambridge UK-based technological and engineering company Epoch Wires has been awarded funding from Innovate UK to design a superconducting machine for future aircraft. The company will collaborate with the University of Strathclyde to develop a new MgB_2 machine model.

The funds were awarded under the Innovate

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UK's competition: UK Aerospace Research and Technology Programme: Collaborative Studies Round One. The total cost of the project is £422,000 ($544.400) with £250,000 ($322,500) funded by Innovate UK.

Epoch to Minimize MgB_2 Wire Filament Size to Reduce AC Losses

The partners will seek to quantify the benefits of an MgB_2 superconducting machine while predicting its utmost limits. Epoch Wires has reportedly identified a method to enable the design of lightweight superconducting machines for future electric aircraft production using MgB_2 wire technology.

"The project will provide a full technology appreciation of how MgB_2 superconducting machines fits into the roadmap of electric aircraft development," commented Epoch Wires CEO Serdar Atamert. "Epoch Wires will design and manufacture a series of multifilamentary wires with different wire architecture aiming to minimize the filament size to reduce the AC losses. The Applied Superconductivity Laboratory at Strathclyde will carry out AC loss measurements at various temperatures and will develop a new MgB_2 machine model using finite element software suitable for large-scale rotational magnetic field modelling, while at the same time achieving accuracy for fine filament modelling to evaluate the machine losses and efficiency.

"The baseline chosen is a fully superconducting synchronous machine since it provides the maximum power density for all machine types. The stator will consist of racetrack coils made of MgB_2 wires. The performance will be compared with propulsion machine roadmaps produced by aviation companies."

MgB_2 Machine Addresses Need to Reduce Aircraft Emissions

Since July 2019, the UK government has added aviation to its net-zero emissions targets. This measure provides an impetus for the development of technologies that would reduce emissions caused by commercial aircraft, an industry that currently contributes to 3% of all global CO_2 emissions.

Electric and hybrid-electric propulsion are expected to be the most promising technologies for addressing these challenges. Since conventional electrical machines and transmission systems cannot meet the necessary high-power density requirements, superconducting electrical distributed propulsion systems could bridge the technology gap for future electric aircraft.

"Epoch Wires have demonstrated that long-length MgB_2 wires can be manufactured with excellent consistency for large-scale applications," Atamert said. "The flexibility of the technology enables the production of small filament sizes required to minimize the AC losses in rotary machines. The combination of long length and consistent quality MgB_2 superconductor operating at 20 K with liquid hydrogen makes this product a potential attractive candidate for aerospace applications."

Epoch Wires was established in 2013, initially to provide superconducting MgB_2 wire to the MRI market. The company uses purified nano-size boron and magnesium powders, from which impurities and undesirable gases are extracted, to produce its wire in a continuous process. It has since aligned its R&D focus to the design of superconducting devices in large scale applications such as power generation and transmission, healthcare and other industrial applications. ❍

Bruker Performance Powers SCW's Stock Index in 2019

Last year was a good year for stocks in general but was even better for *Superconductor Week's* Superconductivity Stock Index (SSI). After falling by 27% in 2018, well behind the S&P's decline of 7%, the SSI rose by 45%, more than doubling the S&P 500's gain of 22%. However, this increase is

somewhat deceiving since, in dollar terms, it was primarily the result of an outstanding year of only one company: Bruker Corp.

The SSI includes publicly traded companies that develop and market superconductivity products. Since not many publicly traded companies have business activities related to superconductors, the Index is highly concentrated. It is market cap-weighted, so the performance of larger companies has a much greater impact on index movement.

Most of these companies have other business activities as well, which means that businesses not related to superconductivity may have an impact on the SSI. And many companies engaged in building superconducting wire or developing applications are not captured by the Index, either because they are private or their involvement in the superconductor industry is a relatively small percentage of their business activities. The latter is the case with many public companies seeking to develop quantum computers, such as Alphabet (Google), Microsoft, IBM, and Intel.

All of the SSI component companies have significant business activity involving superconductors. *Superconductor Week*, therefore, believes that it adequately serves as a proxy for developments in the market for superconducting technologies.

Bruker Restructuring Initiatives Show Results

Bruker's share price rose by 71% in 2019, as many of the measures taken to restructure the company came to fruition. Strong MRI demand propelled the Energy & Supercon Technologies (BEST) segment to higher revenues compared to the previous year. Taking note of this demand, Bruker raised its fiscal year revenue estimates for FY2019 from flat-to-low-single-digits to low-single-digits-to-mid-single-digits.

The Bruker BioSpin Group experienced single-digit revenue growth. Superconducting magnets contributed to this gain, with revenue recognized for two 1.0 GHz NMR systems. Additionally, investors responded to BioSpin energizing a 1.1 GHz NMR system for which it already had customer demand, and its initiation of tests on a 1.2 GHz NMR magnet.

IBA Sees Increase in Proton Therapy Machine Bookings

The share prices of the remaining companies in the SSI declined in dollar terms in 2019. After a couple of difficult years, the shares of Belgian proton therapy manufacturer IBA essentially treaded water, declining by 1% translated into U.S. dollars, although rising by 2% on a constant currency basis.

As the proton therapy equipment market has matured, the demand for systems has moderated and become lumpier. Yet as of mid-year, IBA's order intake from its Proton Therapy and Other Accelerators unit had more than doubled, although most of these bookings did not realize revenues during 2019.

Furukawa Lowers Earnings Estimates

Furukawa Electric's share price fell by 6% translated into U.S. dollars although it rose by 2% on a constant currency basis. Valuations were adversely affected by the company lowering revenue and earnings estimates towards the end of the year. The Energy Infrastructure segment, which includes superconductor activities, had higher revenues but lower operating income, although the latter was higher than had been projected by the company.

Furukawa is included in the index both because of its own production of LTS products and the manufacture of 2G HTS wire by its U.S. subsidiary SuperPower, Inc. The company does not break out financial information for SuperPower, but the subsidiary's revenues were about 30% of combined Furukawa/SuperPower revenues at the time of

their merger in 2012.

AMSC Share Price Returns to Earth

After having advanced by 207% in 2018, AMSC's share price fell by 30% in 2019. There seemed to be no discernible reason for this decline except that the shares may have been overvalued at the end of 2018. GAAP earnings in 2018 reverted to GAAP losses in 2019, but positive 2018 earnings were solely due to one-time income from the settlement of AMSC's long-running legal dispute with Sinovel Wind Group Co. Ltd. (see *Superconductor Week*, Vol 32, No 6).

Most Grid segment revenues continued to be generated by sales of AMSC's non-superconducting D-VAR product, even as the company reported significant progress and revenues from its superconducting Ship Protection systems (SPS) and Resilient Electric Grid (REG) initiatives. With SPS, AMSC began to ramp up for delivery of superconducting components for the U.S. Navy's LPD 28 and LPD 30, and anticipated future orders for other San Antonio class ships (see separate article, this issue).

AMSC also achieved progress with its REG project with ComEd in Chicago, with the U.S. Department of Homeland Security signing off on a contract modification and the Federal Energy Regulatory Commission (FERC) approving the project (see *Superconductor Week*, Vol 33, No 6) . The latter reduces the risk of this type of project by allowing for cost recovery, which AMSC hopes will increase the atttactiveness of REG to utilities.

STI Seeking Strategic Alternatives

The public company that is the purest play for superconducting wire, Superconductor Technologies, Inc. (STI), realized a share price decline of 86%, which followed an 88% decline in 2018. Although the company's Conductus wire has performed well in tests, STI reportedly has had difficulty producing it in large quantities.

Late in the year, STI announced that it was exploring strategic alternatives and had insufficient funds to continue efforts to commercialize its Conductus wire platform. Shareholders, who may have grown tired of waiting for an HTS wire order, turned down a management proposal to split the company's shares (see *Superconductor Week*, No 33, Vol 10).

Two New SSI Additions for 2020

Two companies are being added to the SSSI for 2020: Oxford Instruments (OI) and Western Superconducting Materials Technology Co., Ltd. (WST). OI had been a long-time component of the Index until the end of 2017, when it was dropped due to the sale of its HST wire subsidiary to Bruker at the end of 2016 (see *Superconductor Week*, Vol 30, No 11). It is being added back to the SSI in recognition of its superconducting magnet and growing cryogenics businesses.

WST, a Chinese manufacturer of superconducting NbTi, Nb_3Sn, and MgB_2 wire, made an initial public offering of its shares on Shanghai Stock Exchange's new Science and Technology Innovation Board (STAR market) in mid-2019. Its addition gives the Index exposure to the growing production of superconductor products in China. ❍

Grid Unit Drives AMSC Revenues Higher

AMSC has announced in its Q3 FY2019 earnings release that Grid unit revenues rose by 123.1% to $15.2 million, compared to $6.8 million in revenuess realized in Q3 FY2018. The net operating loss of the segment was $3.7 million, compared to a loss of $2.7 million last year.

The higher revenues were primarily due to an increase in non-superconducting D-VAR sales, although the company's Ship Protection System (SPS) and Resilient Electric Grid (REG) products

contributed as well. Reduced margins due to changes in the product mix resulted in a higher net operating loss. Margins are currently lower on the SPS and REG products while production ramps up.

For the first three quarters of FY2019, Grid revenues increased by 56.8% to $36.6 million from the $23.3 million achieved during the comparable period in FY2018. The operating loss was $9.7 million, slightly higher than the operating loss of $8.2 million from the first nine months of FY2018. Grid revenues constituted 85% of AMSC's aggregate quarterly revenues and 80.0% of aggregate three-quarters revenue.

"Grid revenues more than doubled in the Q3 FY2019, compared to year ago results," commented Daniel P. McGahn, Chairman, President and CEO of AMSC, during the quarterly earnings conference call. "In fact, Grid revenues for the first three quarters of this fiscal year have already surpassed Grid revenues from the entire prior fiscal year. We have maintained our sales momentum, strengthened our backlog and extended our Grid visibility well into fiscal year 2020."

SPS Likely to Provide $150 Million Revenue Stream

McGahn noted that SPS is now the U.S. Navy's baseline design for the San Antonio Class ship platform known as LPD. AMSC is planning to manufacture multiple SPS systems concurrently.

"This fiscal year, we focused on putting into place the capabilities to deliver on the backlog we have already established, SPS systems for LPD 28 and LPD 30," McGahn said. "We are working closely with the Navy to understand the program timing for orders that we anticipate for LPD 29 and LPD 31. We anticipate our SPS has the potential for deployment on a total of approximately 15 future ships in this class.

"We believe our SPS for the San Antonio Class could represent a potential revenue stream of about $150 million over the remaining design life of the San Antonio Class. The Navy has identified the next class of ship for deployment of our SPS system.

"Our long-term vision is to expand HTS technology into the fleet through a variety of applications for power, propulsion and protection equipment. We are pursuing additional classes of vessels with the U.S. Navy, such as aircraft carriers, destroyers, frigates, littoral combat ships and support vessels. With a beachhead established on the San Antonio Class, our strategy is to expand into additional platforms and navies."

Second Chicago REG Project to be 4-6 Times Larger than First

On the REG collaboration with Com Ed in Chicago, McGahn said that AMSC has fabricated the HTS cable and expects to deliver the hardware for the entire project to ComEd in 2020. The energization of REG is expected to occur in 2021.

"We are also working with ComEd to evaluate a second potential project that is expected to be 4 to 6 times larger than the current one," McGahn commented. "The proposed second project is anticipated to link multiple substations in Chicago. We are working to expand REG beyond Chicago. There are issues facing utilities that we believe simply cannot be solved using conventional power delivery systems.

"We continue to pursue specific projects with Boston, Seattle, San Francisco, Washington D.C. as well as Chicago and several other cities. With the first system secured, we believe that the future deployments of REGs will be de-risked. We anticipate growth from our REG business in fiscal 2019."

Aggregate Revenues Higher for Quarter

AMSC's aggregate revenues, including its Wind unit, in Q3 FY2019 rose by 27.0%, to $17.9 million from $14.1 million in Q3 FY2018. The company reported a loss of $6.8 million ($0.35 per share) compared to net income of $17.3 million ($0.83 per share) last year. In Q3 FY2018, AMSC

recorded as income a $25.0 million payment from the Sinovel settlement, which was reached in July of that year (see *Superconductor Week*, Vol 32, No 6).

For the first three quarters of FY2019, AMSC realized $45.7 million in revenues, 9.8% higher than the $41.6 million in revenues achieved during the first three quarters of FY2018. The company reported a loss of $11.2 million ($0.75 per share) compared to net income of $35.1 million ($1.71 per share) during the first three quarters of FY2018.

Cash, cash equivalents and restricted cash at the end of the quarter declined to $66.3 million, compared with $68.6 million at the end of the previous sequential quarter. AMSC's share price rose by 6.4%, from $6.88 to $7.32, on the day after the earnings release.

Net Loss Expected to Decline in Q4 FY2019

For the Q4 FY2019, AMSC expects that its revenues will be in the range of $17.0 million to $20.0 million. Net loss is expected not to exceed $6.0 million, or $0.28 per share.

The company projects operating cash flow to be a burn of $2.0 million to $4.0 million. Cash, cash equivalents and restricted cash at the end of the quarter should be no less than $61.0 million. This guidance does not include any tax payments or other cost related to the final settlement payment from Sinovel. ❍

Bruker BEST Adds Over $700 Million to Backlog

In a preliminary FY2019 earnings release, Bruker Corporation announced that revenue from its Energy & Supercon Technologies (BEST) segment rose by 3.8%, from $55.6 million in Q4 FY2018 to $57.7 million in Q4 FY2019. On an organic basis, BEST segment revenues declined 0.5% year-over-year, net of intercompany eliminations. For FY 2019, BEST segment revenues of $209.9 million increased 7.8% year-over-year from $194.8 million in FY2018, including organic growth of 4.9%, net of intercompany eliminations.

"BEST revenue in 2019 was up in the mid-single digits compared to 2018 on strong superconductor demand from MRI companies," commented Frank Laukien, President and CEO of Bruker, during the company's preliminary earnings conference call. "During the second half of 2019 BEST entered into long-term superconductor supply agreement renewals that in total added over $700 million to BEST backlog. These agreements are for deliveries that are expected over five to seven-year timelines."

Earnings Release Delayed by Income Tax Matters

Bruker had originally planned to announce its FY2019 earnings in mid-February. However, the company recently received an allegation regarding income tax matters involving the effective income tax rate for 2019 and the related income tax balance sheet accounts.

The earnings release was then postponed while the audit committee of the board of directors initiated an internal investigation into the allegation. Accordingly, Bruker was not yet in a position to report final financial results including its tax rate, earnings per share, cash flow and balance sheet.

BioSpin Ships First 1.2 GHz LTS/HTS Magnet

BioSpin Group revenue for FY2019 increased by 5.1% to $621.0 million from $591.1 million the previous year. This reflected growth in both systems revenue and aftermarket as well as a small contribution from software acquisitions. BioSpin also saw continued growth from its NMR food screener and applied magnetic resonance solutions.

"In Q4 FY2019, we achieved additional milestones with our gigahertz class NMR program

for functional structural biology," Laukien said. "We achieved acceptance of the world's first 1.1 GHz system at St. Jude's Children's Research Hospital in the U.S. culminating a decade of R&D on a novel ultra-high field magnet technology that uses a combination of low temperature and high temperature superconductors.

"Similar hybrid LTS/HTS technology is also used in our 1.2 GHz NMR magnets for which we have considerable backlog. During the fourth quarter, we also received the first orders for 1.2 GHz NMR systems from the U.S. and South Korea. We shipped the first 1.2 GHz NMR in Europe which has now arrived at the customer site with installation expected in the first half of 2020."

Bruker Realizes Higher Revenues and Operating Income

For the company as a whole, Bruker announced revenues of $599.9 million for Q4 FY2019, 8.4% higher than Q4 FY2018 revenues of $553.6 million. Growth from acquisitions was 4.3%, constant currency growth was 9.5%, and foreign currency translation had a negative effect of 1.1%, resulting in organic revenue growth of 5.2%. Operating income rose by 10.6% to $117.7 million compared to $106.4 million during the comparable period.

For FY2019, Bruker revenues reached $2072.6 million, 9.3% higher than the $1895.6 million realized during FY2018. Organic revenue growth was 5.7% year-over-year. Growth from acquisitions was 6.3%, constant currency growth was 12.0%, while foreign currency translation had a negative effect of 2.7%.

Bruker's operating income for the year grew by 14.7% to $300.9 million from $262.4 million in FY2018. Cash and cash equivalents on the balance sheet were $678.3 million at the end of the year, compared to $302.4 million at the end of Q3 FY2019. The company's share price fell by 2.5%, from $50.51 to $49.25, on the day of the earnings announcement.

"Our fourth quarter capped off a strong year for Bruker operationally," Laukien said. "Our revenues exceeded $2.0 billion for the first time, and Bruker's non-GAAP operating margin reached 17.6%. We believe we enter 2020 well-positioned to continue to drive profitable growth."

For FY 2020, Bruker projects year-over-year organic revenue growth of 4.0% to 5.0% and non-GAAP operating margin expansion of 70 to 90 basis points compared to FY 2019. The company will provide FY 2020 earnings per share guidance, when reporting its FY 2019 financial results. ❍

NIST Outlines Methods for Measuring SPDs

Researchers from the U.S. National Institute of Standards and Technology (NIST) have published methods for measuring the efficiency of two different types of single photon detectors (SPDs) (doi.org/10.1088/1681-7575/ab4533). Their work is an initial step towards toward creating universal standards for these devices and establishes a reference for NIST's planned calibration service.

In the years since NIST developed the initial optical superconducting SPD in the early 2000s, these devices have become an important research tool for counting photons, and for applications ranging from optical communications and astrophysics to advanced information technologies based on quantum physics, such as quantum cryptography and quantum teleportation. However, no standard currently exists for ensuring their accuracy and reliability.

Ten Metrology Institutes Collaborating on SPD Measurement Standard

In the modern form of the metric system, the SI, the basic unit of measurement that is most closely related to photon detection is the candela (cd), which is relevant to light detected by the human eye. However, the SI is being recast based

on fundamental constants and laws of nature. This might lead to a source- or detector-based single-photon standard, a reason why many national metrology institutes around the world are pursuing the establishment of single-photon-based traceable or absolute calibrations of single-photon detectors and sources.

"There is an ongoing international comparison for single photon detector efficiency measurements," commented NIST researcher Thomas Gerrits. "PTB (Physikalisch-Technische Bundesanstalt, Germany) is leading this effort, and NIST participates; a total of ten metrology institutes are involved. The calibration of SPDs would be the first step or baseline tool for verification of a single-photon standard once it is developed."

NIST is especially qualified to develop evaluation methods for SPDs because it fabricates the most efficient single photon devices in the world. The institute specializes in two superconducting designs: one based on nanowires or nanostrips, the subject of the current study, and the other based on transition-edge sensors (TESs), which are to be studied in the near future. Additional work may also address standards for detectors that measure very low light levels but cannot count photons.

"The development of superconducting technologies such as superconducting nanowire single-photon detectors (SNSPDs) and TESs for single photon detection have been primarily driven by the demands of quantum information science and technology applications in which high efficiency, low false counts, low jitter are critical and are needed at any cost," Gerrits said. "Other applications of SPDs in spectroscopy, astronomy, astrophysics, automatic soap dispensers, lidar, etc., may value other things more importantly like cost, size, weight, and power consumption. In those cases, a [non-superconducting] single-photon avalanche diode (SPAD) may be more appropriate to use."

Five Detectors Measured for Detection Efficiency

The NIST team used conventional technologies to measure the detection efficiency, the probability of detecting a photon hitting the detector and producing a measurable outcome, of five detectors at two wavelengths that are commonly used in fiber optics and communications. Four, consisting of one free-space silicon SPAD (8103) using two different lasers, two optical fiber-coupled Si-SPADs (V23172 and V23173), and one fusion-spliced superconducting nanowire SNSPD (PD9D), were measured at a wavelength of about 851 nm. In addition, a fiber-coupled SNSPD (NS233) using fusion splice and a commercial fiber connector was measured at a wavelength of 1533.6 nm.

"In practice, the commercial fiber connector is the most convenient to use, as you just plug two fibers into a fiber-to-fiber union," Gerrits noted. "However, since the fiber core is so small (~10 microns), small misalignments lead to loss at the connection, and this loss is different for different fiber connectors.

"Fusion splicing is less practical, but more repeatable. Thus, this comparison illustrates the problem in identifying proper uncertainties when using connectors."

The team ensured that their measurements would be traceable to NIST's Laser Optimized Cryogenic Radiometer, a primary standard for optical power meters. These meters maintain accuracy for measurements at low light levels, when overall measurement uncertainty is mostly due to the power meter calibration. This capability can, in principle, bridge a gap between single-photon counting, femtowatt (fW) and nanowatt (nW) power levels.

Detector Tomography May Be Used to Study TES Standards

The researchers corrected for afterpulsing, dark count, and the count-rate effects of each single

photon detector with the detection efficiency interpolated to operation at a specified detected count rate. They determined that the expanded relative uncertainty for a single measurement of the detection efficiency ranged from a low of 0.70% for fiber-coupled measurements at a wavelength of 1533.6 nm to a high of 1.78% for free-space characterization at 851.7 nm.

Gerrits commented on the challenges of following up this work by studying standards for TESs: "The TESs are on the radar, especially as they are photon-number resolving. However, we do not have photon sources that produce 2,3,4,… photons only. We only have weak laser beams that emit a random number of photons at any given time.

"In addition, the efficiency is only one number and cannot fully describe the response of an SPD. In order to do this and determine the 2,3,4… photon response of a TES, one needs to perform detector tomography, which allows for mapping out the 'nonlinearity' of the SPD - that is, given an efficiency eta for getting a single photon detector outcome for only one single photon coming in, can one predict the detector outcome for an arbitrary number of photons coming in, or whether there is there a non-linear response/ different eta for different incoming photon numbers This tomography method, although more difficult to implement, would be very useful to fully characterize the TESs." ❍

St. Jean Carbon to Develop Superconducting Graphene Wire

Canadian carbon sciences company Saint Jean Carbon Inc. has entered into a collaboration with Los Angeles-based K-Technology USA Inc. to develop a superconducting graphene wire based on Saint Jean's provisional patent application for creating a diamagnetic superconducting wire. The goal of the project is to conceptualize the necessary engineering to produce a prototype wire.

"There are two big advantages to graphene based superconducting wire," commented Saint Jean CEO Paul Ogilvie. "First, graphene is very cheap to make and second, unlike other superconducting wire projects that are trying to build special materials for conductivity and design, graphene starts out as the best material in the world as far as conductivity is concerned. Also, natural graphite used as the graphene base eliminates all the issues with chemical vapour deposition based graphene."

U.S. Patent Pending on Graphene Wire Design

St. Jean's pending patent describes a wire with an outer housing that is a non-conductive rubber compound, an inner sleeve that is a resin binder with a high concentration of diamagnetic graphene, and a center core that is a magnetic graphene wire. The diamagnetic force holds the center core in place while the energy passes along the path of the neutralized middle core.

St. Jean has the advantage of access to very pure base graphite extracted from its own mines for its research, which minimizes the need for costly and environmentally harsh purification. The graphene produced from this graphite has demonstrated excellent electrical/thermal connectivity, large high surface area and very good wettability.

Research Demonstrated Efficacy of MAPLE Wire Production

Since filing for its patent, St. Jean has conducted research with Western University to better understand the material characteristics of graphene (see *Superconductor Week*, Vol 29, No 12). The team demonstrated the effectiveness of using matrix-assisted pulsed laser evaporation (MAPLE) to deposit superconducting YBCO particles on graphene sheets and observed that YBCO nanoparticle size is a function of irradiation time. Their work could offer an alternative method to produce ultra-thin HTS materials in an easy and controllable fashion.

"The project gave us a way to create a graphene wire and a technique for filing in the 'gapping' issues," Ogilvie said. "This has led us to coin a new term for the wire project. We have filed a patent for a true superconducting cable/wire; however, with the project with Western, we discovered a hyper-conducting wire, significantly better and cheaper than copper wire, but not quite superconducting."

Collaboration to Develop Energy Storage System

K-Technology is building a graphene power energy system. In a patent issued last November, this is described as being connected to a rotating shaft or driving shafts of the vehicles or other moving objects. The wasting energy from these shafts would be re-collectable by a nano-graphene alternator or generators when rotating the shafts.

The system would be fabricated with lightweight but ultra-strong materials, with graphene wire used instead of copper wire. St. Jean plans to produce magnetic hyper-conducting wire for the alternator and superconducting graphene wire for the connection between the alternator and the energy storage. In its patent abstract, K-Technology estimated that this system would reduce size and weight by about 70%.

According to Ogilvie, St. Jean has worked through the mechanically engineering design concepts on how to build the wire. In addition, its research team has reviewed all possible raw materials needed, and has established a variety of test protocols for the first prototype wire.

The project is scheduled for completion in late spring or early summer. St. Jean is forming a separate company that will only concentrate on wire development and manufacturing.

Until now, St. Jean has largely self-funded the development of its graphene wire. The company is looking for investment partners to help build out its technology. Ogilvie encourages anyone interested in the project to please reach out to the company. ❍

Furukawa Reports Lower Revenues and Income for Three Quarters of FY2010

The Furukawa Electric Co., Inc., the parent company of SuperPower, Inc., has announced that revenues for the first three quarters of FY2019 fell by 8.4% to ¥676.2 billion ($6.2 billion) compared to ¥738.6 billion ($6.7 billion) over the first three quarters of FY2018. Net income reached ¥7.4 billion ($67.8 million), or ¥105.7 per share, compared to ¥18.1 billion yen ($170.2 million), or ¥265.1 per share) the year before, a 60.1% decline. Furukawa's share price rose by 2.0%, from ¥2580 to ¥2632, on the day of the earnings announcement.

Furukawa's Electronics Component Materials segment revenues, which include its superconducting products, were ¥193.4 billion ($1.8 billion) for the period compared to ¥220.9 billion ($2.0 million) the previous year, a year-over-year decline of 12.4%. This segment reported operating income of ¥2.6 billion ($23.6 million), 44.7% lower than the ¥4.7 billion ($42.8 million) reported during the earlier period. The company noted that demand for electronics products weakened further than expected and should continue to be weak in the fourth quarter.

Earnings Estimates for FY 2019 Lowered

Based on these results, Furukawa reduced its earnings estimates for the fiscal year. Among the primary reasons for this adjustment, the company cited falling optical fiber and cable prices in Europe and Asia, the delay in improving optical cable productivity in North America, the continued weak market for electronics and automotive systems, and increased expenses related to a copper foil plant in Taiwan.

Furukawa now expects aggregate revenues for the year to be ¥900.0 billion ($8.2 billion) instead of ¥910.0 billion ($8.3 billion), and net income to be ¥10.0 billion ($91.1 million) instead of ¥11.0 billion ($10.0 million). Electronics Component Materials segment revenues are now expected to

reach ¥255.0 billion ($2.3 billion) instead of ¥260.0 billion ($2.4 million). ❍

ORNL Demonstrates Josephson Cryogenic Memory Cell

Researchers at the U.S. Department of Energy's Oak Ridge National Lab (ORNL) experimentally demonstrated a functional cryogenic memory cell consisting of three inductively coupled Josephson junctions (doi.org/ 10.1088/1361-6668/ab416a). The design, novel to this research project, gives each cell the capacity to read, write, and reset individually, which adds stability and computing speed while saving space and energy. The cells could prove especially beneficial in large arrays and could help advance quantum and exascale computing.

Chief ORNL researcher Yehuda Braiman commented: "The proposed memory design allows for multivalued memory cells; the ternary memory cell [is] the first step in this direction. In the near future, people will be able to build mission oriented stand-alone computing devices based on Josephson junction technology."

Cells Functioned Within a Wide Array of Parameters

Superconducting digital logic circuits show great promise in improving computing speed while reducing energy costs, but to date developing scalable RAM for supercomputing circuits has proven problematic. Researchers at ORNL have sought to surmount these problems by developing minimal individually addressable memory cells with few terminals and junctions.

The ORNL design employs three small inductively coupled arrays of Josephson junctions functioning at 4 K, which use the same operating principles as a binary memory cell. Recent experiments at ORNL demonstrated a robust functionality of the cells that were able to operate within a wide array of experimental parameters.

"The structure of the cell is based on a small array of coupled Josephson junctions, and the logic is based on the location and number of magnetic flux quanta stored between them," Braiman explained. "This is different from the previously proposed cryogenic memory cells.

"It is indeed remarkable that such a small array consisting of only three coupled junctions possesses so many stable phase configurations that could be considered for memory states. As it is common for Josephson junction-based technology, transitions between the states can be very fast (on the level of picoseconds) and the energy requirement for such transitions may be very low (at the level of 0.1-1 attojoules)."

According to Braiman, the results indicate that the memory cells are robust to many of the errors commonly inevitable in any fabrication process: "Such robustness to parameter choice is certainly important for future design of memory cell arrays. Overall, it is premature to either over- or underestimate the significance of the proposed memory cells. People need large memory cell arrays and it remains to be seen whether and how such arrays could be built."

SeeQC Fabricated and Tested Chips Based on Design

Prior to experimentation, the team ran simulations using WRspice circuit simulator software, considered to be highly reliable in modeling Josephson junction circuits. The results were surprising, as they demonstrated an increased experimental parameter range for stable operation and robustness of the operations to fabrication parameter variations.

ORNL teamed with superconducting tech company SeeQC to test their cell circuits. SeeQC fabricated the ORNL design onto 5x5 mm chips with circuits on each corner, which were then mounted onto a cryogenic probe and submersed in liquid helium and cooled to 4 K. The chips were connected by wire to a computer at room

temperature, which sent electric pulses to test the cells function.

Braiman opines that the greatest challenge in experimentation "was the inherent nonlinearities existing in Josephson junctions. This means that any change in the circuitry, including peripheral circuits, should be carefully addressed and taken into account in selecting design parameters."

Although it is hard to make predictions about the degree of success, Braiman noted that the team is optimistic that it will be possible to design, fabricate, and build large memory cell arrays based on the proposed cells. As of yet, the cells have only demonstrably performed in single cell units; the potential benefits of the application will only be fully realized once the circuits are demonstrably functional in greater scales.

Larger Cell Arrays to be Fabricated

The researchers are currently revamping their lab to allow for the creation of larger cell arrays. They plan to start with smaller arrays, in the 10x10 range, but hopefully will move on to fabricating substantially larger arrays.

"Part of puzzle is also future availability of funding for this work," Braiman said. "People have tried to build large memory arrays based on Josephson junction technology but so far it has not been successful to meet all the required/desirable criteria. Consequently this makes it more challenging to convince funding agencies to keep on investing in cryogenic memory work."

This project was funded by U.S. Department of Energy's Office of Advanced Computing Research through the Sawtooth project, with the goal of investigating integrated solutions to the challenges of performance and power consumption in supercomputer memory systems. ❍

Johns Hopkins Observes Novel Properties of SC β-Bi_2Pd

Researchers at Johns Hopkins University have discovered that a ring of superconducting β-Bi_2Pd exists between two states without an external magnetic field, allowing the current to circulate both clockwise and counterclockwise simultaneously (DOI: 10.1126/science.aau6539). With these unique properties, the material could potentially contribute to the advancement of quantum computing.

Quantum computers are able to encrypt data more securely and process information at faster speeds. However, there are a number of obstacles preventing the development of building a large-scale quantum computer. These include, but are not limited to, physical scalability, quantum gates able to work within the decoherence time, a universal gate set, and easily read qubits.

At low temperatures, superconductors expel an applied magnetic field, and for those with a nontrivial topology, there can exist a non-zero flux within the hole, which is able to take certain discrete values. These superconductors have maximum critical temperatures at corresponding values to their magnetic field in what is known as Little-Parks oscillations.

Oscillations Shift by π Compared to Other Superconductors

Yufan Li, one of the Johns Hopkins researchers spearheading this research, explained the effect: "Quantized flux means the superconductor may need to sport a circulating current, when the external field fails to provide the ideal quantization values. Mobilizing electrons costs energy. Therefore, flux quantization affects the energy landscape of a superconductor, which manifests as the Little-Parks effect."

In experimentation, the Johns Hopkins team studying Little-Parks oscillations in rings of polycrystalline thin films of β-Bi_2Pd, found a shift

equal to π when compared with oscillations in most superconductors. They verified the unconventional superconductivity of β-Bi_2Pd, noting that it could be expected to be a topological superconductor and is a candidate for spin triplet superconductivity.

Li suggested that, since the superposition of two basis states can be achieved without an external field, β-Bi_2Pd eliminates noise induced by external magnetic flux. Reducing sources of noise would help to achieve longer decoherence time. This may prove that β-Bi_2Pd is cost effective for scaling qubits.

Conditions Exist for Majorana Fermions

With spin triplet superconductivity a possibility, the researchers suggested that thin films of β-Bi_2Pd hold the properties necessary for Majorana fermions to exist. These particles are also anti-particles of themselves, and might be used to develop for disruption resistant quantum computers.

"It is a quasi-particle that can be seen as one half of an electron," Li noted. "Two Majorana fermions make one electron but the two can be separated and placed in distant locations. Noise occurring at one location should not be able to alter the physical state of the dual.

"It is precisely because of the π phase shift that we have the superposition of CW and CCW current at zero field. This is a rather unique effect, made possible by the elusive spin-triplet pairing, although the effect itself is not related to Majorana fermions. A spin-triplet superconductor would almost certainly support Majorana fermions."

Li and his team are now working to develop a flux qubit that takes advantage of the π phase shift. They are also seeking evidence of Majorana fermions in the material.

This work was supported by the U.S. Department of Energy, Basic Energy Science, award award grant no. DESC0009390. ❍

Brookhaven Raises Surface Conductance in a Topological Insulator

Researchers at Brookhaven National Lab have fabricated microdevices with a focused ion beam from an indium-doped topological insulator $Pb_{1-x}Sn_xTe$ that enhance the surface contribution of the total conductance (doi.org/10.1063/1.5122789). In addition, 2D superconductivity emerged below 6 K. These results demonstrate that the engineering of single crystals can achieve interesting electronic responses relevant to practical applications and might be used for the development of new techniques to fabricate in-situ superconducting circuits on top of crystalline materials, as doped electrons are controlled by micromachining patterns.

"This research is a consequence of earlier work within the Center for Emergent Superconductivity, an Energy Frontier Research Center that is led by Brookhaven National Lab," commented Brookhaven researcher Yangmu Li. "We have sought to discover new superconductors and improve the performance of superconductors by understanding the fundamental physics of superconductivity."

Ion Beam Machining Enables Better Control of Device Geometry

Controllable geometric manipulation via micromachining techniques provides a promising tool for enhancing useful topological electrical responses relevant to future applications such as quantum information science. Focused ion beam machining, which offers considerable flexibility in precise control of device geometry, has recently been applied to study topological materials, strongly correlated materials, and unconventional superconductors, and enables convenient and well-controlled micromachining of hard crystalline materials with which lithography usually has difficulty. Past research has demonstrated that the geometric control of quantum devices is an effective method for manipulating surface and

bulk responses.

The Brookhaven scientists fabricated two microdevices with extremely large bulk resistivity, the first, 84.0 x 23.0 x 0.5 µm3, and the second, 75.0 x 30.3 x 1.8 µm3, from the same In-doped bulk crystal of $Pb_{1-x}Sn_xTe$ [$(Pb_{1-x}Sn_x)_{1-y}In_yTe$ with x = 0.4 and y = 0.08]. Near room temperature, they achieved an enhancement of the surface contribution to about 30% of the total conductance.

Weak Antilocalization Behavior Revealed

As the temperature was reduced, the surface contribution increased. It became dominant below approximately 180 K, compared to 30 K in millimeter-thickness crystals.

The team measured magnetoresistivity at high magnetic fields. This revealed a weak antilocalization behavior in the normal-state magnetoconductance at low temperatures and a variation in the power-law dependence of resistivity on temperature with the field.

"The weak antilocalization signifies that the dominant conductance contribution in our sample is associated with topological surface states," Li noted. "In comic-book terms, these surface states have a superpower such that they can tunnel right through defects that would scatter any 'normal' electron.

"The kryptonite for these surface states is magnetism, so the applied magnetic field causes an increase in resistance (scattering) of the surface electrons. The variation in the power-law dependence at low temperature suggests that the superconducting state is highly unusual and might have a connection with the topological surface state."

Micromachining Resulted in Drop in Resistivity

The team observed at drop in resistivity below 6 K, which suggested the emergence of 2D superconducting fluctuations, a state that is not present in the parent crystal. A slightly higher indium concentration may have contributed to this drop, which only reached zero below 0.4 K.

"The surface contribution to the total conductance is determined by the thickness of the two devices," Li said. "The large surface contribution is associated with thinner samples. The drop in resistivity or superconductivity is associated with the surface conditions after micromachining."

Li commented on how the team would build on these findings: "We plan to further study the focused-ion-beam-machining-induced superconductivity on other correlated and topological materials and potential applications.

The work received financial support from the Office of Basic Energy Sciences, Materials Sciences and Engineering Division, U.S. Department of Energy under contract no. DE-SC0012704. ❍

Superconductivity Roundup

Events & Opportunities from Around the Industry

Superconductor Technologies Inc. (STI) has implemented a **cost reduction plan** for the purpose of aligning its personnel needs and capital requirements as it explores strategic alternatives that previously had been announced (see *Superconductor Week*, No 33, Vol 10). The company will continue its Sapphire Cryocooler cryogenics initiatives while **ceasing additional manufacturing of its HTS Conductus wire**.

The plan also includes a **70% employee workforce reduction**. As a result of the cost reduction plan, management anticipates that it will not incur any significant charges for severance or other employee termination related costs.

Recent **developments in particle theory systems and techniques** were discussed at the **Physics-based Contributions to Medical**

Techniques (PCMT) conference which took place late last year. **University of Manchester researcher Hyel Owen** spoke about his work in developing **a superconducting cyclotron, which operates at 70 McV**. The Cockroft Institute of Warrington, UK, and the Antaya Technologies Corp. of Warwick, RI are collaborating to produce a prototype of this device.

The **Cockroft Institute, the Christie NHS Foundation Trust, and CERN** are working on a joint project to develop **a proton boosting extension for imaging and therapy (PRoBE) linac** designed to accelerate protons from medical cyclotrons to the higher energies required for proton imaging. The manufactured proton cavity is predicted to achieve a gradient of 54 MV/m.

Simon Jolly of the University College of London (UCL) spoke about **improving proton beam accuracy**. UCL has developed a device similar to multilayer ionization chambers, but employing individual sheets of plastic scintillator instead of stacked ionization chambers.

A proton beam is shot horizontally into the scintillator sheets, where a pixellated sensor reads the light signal from each individual sheet, and the beam range is estimated based on the light distribution. The machine has a proton range reconstruction accuracy of 100 μm and is capable of surviving 6500 Gy with less than a 5% reduction in peak light output and no change in range accuracy.

sw The **Japan National Institutes for Quantum and Radiological Science and Technology (QST)** and **Mitsubishi Heavy Industries (MHI)** have built the **world's largest superconducting toroidal field (TF) coil** for the **ITER experimental fusion reactor project** in France. The coil is the first main structural component for ITER's magnet system, and its completion is a major milestone forward for the reactor's construction. Plans call for five TF coils to be produced at the Futami Plant, which will be shipped to southern France in early March in the run-up to the start of ITER operations in 2025.

ITER's superconducting TF coils are D-shaped and approximately 16.5 meters in height, 9 meters wide, and weigh some 300 tonnes. Eighteen TF coils will encompass the vacuum vessel container and generate a powerful magnetic field (maximum of 12 T) to confine high-temperature, high-density plasma within the vessel.

The ITER Project requires a total of 19 TF coils to be made: 9 in Japan (including the spare) and 10 in Europe. The inner coil structures for all 19 TF coils will be manufactured at MHI's Futami Plant. **Mitsubishi Electric Corporation** is in charge of producing the **Nb_3Sn superconducting winding packs** for five TF coils, including the newly completed coil, with the outer coil structures being manufactured in Korea, and final assembly performed at Futami.

sw **Fermi National Accelerator Laboratory (Fermilab)** engineer and physicist **Alvin Tollestrup**, who played a key role in developing the Tevatron as a leading high-energy physics accelerator, has **died of cancer** at the age of 95. Tollestrup led the team that designed and tested the **1,000 superconducting magnets used in the Tevatron**, which operated from 1983 until 2011 and for 25 years was the world's most powerful particle collider.

The Tevatron led to the discovery of two fundamental particles: the **top quark and the tau neutrino**. The top quark, discovered in 1995, was the last undiscovered particle of the six-member quark family that explains the composition of protons, neutrons and other particles. The discovery of the tau neutrino with the Tevatron accelerator followed in 2000.

Tollestrup received his bachelor's degree in engineering from the University of Utah in 1944. After service in the U.S. Navy, he entered graduate school at the California Institute of Technology, where he earned his Ph.D. in physics in 1950. He remained at Caltech to build the electron synchrotron and joined the Caltech faculty.

Tollestrup moved to Fermilab 1975 and later became head of the newly created **Collider**

Detector Facility. During the 1990s he became a founding member of the Neutrino Factory and Muon Collider collaboration, today known as the **Muon Accelerator Program**.

In 2009, along with **Florida State University's David Larbalestier**, Tollestrup successfully launched and led the **Very High Field Superconducting Magnet Collaboration**, which significantly increased the current density of a bismuth-based superconducting material. He received many honors during his career, including the National Medal of Technology and was elected to the National Academy of Sciences.

sw **Assistant Professor Tian Zhong** of the **University of Chicago's Pritzker School of Molecular Engineering (PME)** recently received a **National Science Foundation (NSF) Faculty Early Career Development (CAREER) award** of $500,000 over a five-year period for his research proposal on **creating a quantum internet**. The research project, entitled **"Long-distance quantum network of long-lived rare-earth qubits"** aims to give internet users the power of quantum computing by distributing entanglement and exchanging quantum information on a global scale.

Currently, the distribution of quantum-secured cryptographic keys over a network link has been realized, but only at distances no greater than about 100 km due to the intrinsic loss of optical fibers. Zhong's research focuses on using individual rare-earth atoms in solids to realize a repeater node. The rare-earth atoms, specifically erbium (Er), offer long quantum coherence times and emission at a wavelength that is compatible with existing telecommunication infrastructure. Once deployed, this type of network would enable many applications ranging from quantum cryptography, which promises secure communication, to blind quantum computing, to enhanced quantum sensing.

The project also highlights outreach activities to engage women and underrepresented students in Chicago public high schools. In collaboration with the STAGE Lab, Zhong is helping to explore new forms of art that convey ideas of quantum science to a broader audience.

sw Researchers with **Saitama University** have published a paper describing how **superconducting micro-resonators work as high-sensitivity photon detectors**, from millimeter-wave signals to high-energy particles (doi.org/10.2221/jcsj.54.174). The resonators are called microwave kinetic inductance detectors and are suitable for use in a large format array.

Microwave kinetic inductance detectors are easily fabricated applying a few photolithographic processes, and the resonator yield is more than 90%. Hundreds of superconducting resonators can be biased with a single readout line, enabling them to be read out together with frequency multiplexing.

In the study, the team described the recent progress of scientific projects relying on this technique, and summarize results for millimeter-wave astronomy and a high-energy particle detection system. They fabricated a device using epitaxial aluminum on a silicon wafer and its noise was as low as the background limit, approximately 6 10^{-18} W/Hz$^{1/2}$ in the millimeter-wave range.

For high-energy particle detection, the researchers investigated two materials: niobium and a YBCO. The niobium-based device detected the alpha line (5.4 MeV) events. The pulse decay time was approximately 5 μs and energy resolution was approximately 1 MeV.

sw **Clark University** physics professor **Chuck Agosta** has received a **$670,000 grant** from the **National Science Foundation (NSF)** to support his superconductor research into **high magnetic fields**. NSF's initial award to Agosta of $440,000 was bumped up to $670,000 to include a liquefier for recycling helium. Agosta's project is entitled **"Charge modulation in unconventional superconductors"**.

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

~Insert~

February 20, 2020 Vol. 34, No. 1

Superconductivity Stock Index

Company Name	Symbol	Prices ending 31-Dec-2019	Prices ending 31-jan-2020	Percentage change
American Superconductor	AMSC	7.85	6.28	-20%
Superconductor Technologies	SCON	0.18	0.24	33%
Bruker Corporation	BRKR	50.97	49.47	-3%
Furukawa Electric	5801	25.83*	24.01*	-7%
Ion Beam Application	IBAB.BR	14.63*	11.52*	-21%
Oxford Instruments	OXIG.L	20.34	20.36*	0%
Western Superconducting	688122.SS	4.85	5.25*	8%
Superconductor Index (12/31/19 = 100)		100.00	97.21	-3%
Standard and Poor's 500		3,230.78	3,225.52	0%

The Superconductivity Stock Indes is a market value index as is the S&P 500. 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.

* Share price is converted to U.S. dollars

U.S. Superconductivity Patents

Methods of manufacturing SC and phononic elements

Leiden University
October 8, 2019
U.S. Patent No. 10,439,125

The method of manufacturing a SC element comprises the step of forming a periodic patterned structure in a material to alter an electronic structure in a primary layer to couple with each phonon of the primary layer so as to induce superconductivity in the primary layer or modify the superconductivity, and/or create or alter one or more phonons to couple with the electrons so as to induce superconductivity or modify the superconductivity of the primary layer. The method of manufacturing a phononic element comprises the steps of: providing one of a primary and a secondary layer of a material on the other of the primary and secondary layesr of the material; and forming a periodic patterned structure in the secondary layer to create or alter one or more phonons in the primary layer.

Vertical SC capacitors for transmon qubits

IBM Corp.
October 15, 2019
U.S. Patent No. 10,445,651

A vertical q-capacitor includes a trench in a substrate through a layer of SC material. A SC is deposited in the trench forming a first film on a first surface, a second film on a second surface, and a third film of the SC on a third surface of the trench. The first and second surfaces are substantially parallel, and the third surface in the trench separates the first and second surfaces. A dielectric is exposed below the third film by etching. A first coupling is formed between the first film and a first contact, and a second coupling is formed between the second film and a second contact in a SC quantum logic circuit. The first and second couplings cause the first and second films to operate as the vertical q-capacitor that maintains integrity of data in the SC quantum logic circuit within a threshold level.

Coated conductor HST carrying high J_c under magnetic field by intrinsic pinning centers

Superconductor Technologies Inc.
October 15, 2019
U.S. Patent No. 10,446,294

A coated conductor comprises a substrate supporting a ReBCO SC adapted to carry current in a SC state. The SC

is characterized in having peaks in critical current (J_c) of at least 0.2 MA/cm^2 in a magnetic field of about 1 T when the field is applied normal and parallel to the surface of the SC, and further characterized in that the SC includes horizontal and columnar defects in a size and an amount sufficient to result in the said critical current response. The conductor is characterized in that the ratio of the height of the peaks in the J_c is in the range from 3:1 with the ratio of the field perpendicular (0 degrees) to the field parallel (+/-90 degrees) to the range from 3:1 with the ratio of the field parallel to the field perpendicular.

Backside coupling with SC partial TSV for transmon qubits

IBM Corp.

October 15, 2019

U.S. Patent No. 10,446,736

A capacitive coupling device (superconducting C-coupler) includes a trench formed through a substrate, from a backside of the substrate, reaching a depth substantially orthogonal to a plane of fabrication on a frontside of the substrate, the depth being less than a thickness of the substrate. A SC material is deposited as a continuous conducting via layer in the trench with a space between surfaces of the via layer remaining accessible from the backside. A SC pad is formed on the frontside, the SC pad coupling with a quantum logic circuit element fabricated on the frontside. An extension of the via layer is formed on the backside. The extension couples to a quantum readout circuit element fabricated on the backside.

SC devices, such as slip-rings and motors/generators

Moog, Inc.

October 15, 2019

U.S. Patent No. 10,446,995

A device (i.e., a slip-ring or a homopolar motor/generator) is adapted to provide electrical contact between a stator and a rotor, and includes: a current-carrying brush-spring mounted on the stator, and having two opposite surfaces; a fibrous brush assembly mounted on the conductor, the brush assembly having a bundle of fibers arranged such that the tips of the fibers will engage the rotor for transferring electrical current between the stator and rotor; a ribbon of SC material mounted on each opposite surface of the current-carrying brush-spring and communicating with the stator and the brush assembly; and another ribbon of SC material mounted on the rotor. The device is submerged in a cryogenic fluid at a temperature below the $T_c$ís of the SC materials such that the electrical resistivity of the device will be reduced and the current-transfer capability of the device will be increased.

JTL-based SC logic arrays and FPGAs

Northrop Grumman Systems Corp

October 15, 2019

U.S. Patent No. 10,446,995

SC logic arrays (SLAs) and field-programmable gate arrays (FPGAs) that are based on Josephson transmission lines (JTLs) accommodate reciprocal quantum logic (RQL) compliant binary input signals and provide RQL-compliant output signals that are evaluations of generalized logic functions. Each JTL-based SC FPGA (JTLBSFPGA) incorporates multiple JTL-based SLAs (JTLBSLAs) connected together. Each JTLBSLA includes an array of software-programmable and/or mask-programmed logic cells that output products of inputs and cell states, such that the JTLBSLAs output evaluations of sum-of-products functions. New JTLBSLA logic cells are described, including some that provide programmable cell states via magnetic Josephson junctions. JTLBSFPGAs provide area efficiency and clock speed advantages over CMOS FPGAs. Unlike SLAs based on Josephson magnetic random access memory, JTLBSLAs do not require word line drivers, flux pumps, or sense amplifiers. Because JTLBSLAs and JTLBSFPGAs are RQL-compliant, they can also include RQL gates connected within or between them, without signal conversion circuitry.

Nanoparticles for the use as pinning centers in SCs

BASF SE

October 22, 2019

U.S. Patent No. 10,450,199

The invention is in the field of nanoparticles, their preparation and their use as pinning centers in SCs. In particular it relates to nanoparticles comprising an oxide of Sr, Ba, Y, La, Ti, Zr, Hf, Nb, or Ta, wherein the nanoparticles have a weight average diameter of 1 to 30 nm and wherein an organic compound of general formula (I), (II) or (III) or an organic compound containing at least two carboxylic acid groups on the surface of the nanoparticles (I) (II) (III) wherein a is 0 to 5, b and c are independent of each other 1 to 14, n is 1 to 5, f is 0 to 5, p and q are independent of each other 1 to 14, and e and f are independent of each other 0 to 12.

Densified SC materials and methods

Florida State University Research Foundation, Inc.

October 22, 2019

U.S. Patent No. 10,450,641

Methods of pre-densifying a metal wire containing SC materials and SC materials containing the pre-densified wires are provided. The wires may be pre-densified by subjecting a metal wire that includes one or more filament cavities in which a SC precursor powder is disposed to a

temperature and a first pressure for a time sufficient to densify the SC precursor powder to form a pre-densified metal wire, wherein the temperature is less than the melting point of the SC precursor powder, and the first pressure is sufficient, at the temperature, to compress at least a portion of the metal wire.

Cryogenic cooling system and method

General Electric Co.

October 22, 2019

U.S. Patent No. 10,451,318

A cryogenic cooling system (CCS) includes a cylindrical housing having a first end and a second end. Also, the CCS includes a displacer disposed within the cylindrical housing and reciprocatingly driven between the first and second ends of the cylindrical housing to compress or expand a refrigerant gas in a gas chamber. Further, the CCS includes a tubing unit coupled to the second end of the cylindrical housing and disposed adjacent to at least one SC unit, wherein the tubing unit is configured to circulate the refrigerant gas received from the cylindrical housing through the tubing unit to absorb at least one heat load imposed on at least one SC unit to generate heated refrigerant gas, and convey the heated refrigerant gas to the gas chamber of the cylindrical housing to reduce or maintain a temperature of the at least one SC unit.

SC and method for SC manufacturing

University of Houston System

October 22, 2019

U.S. Patent No. 10,453,590

A SC article comprising a silver overlayer consisting of no more than about 20% of grains over about 1 .mu.m, having a minimum Vickers micro-hardness value of about 100, and a porosity of less than about 1%. A method of manufacturing a SC tape is disclosed as comprising, deposition of silver, oxygenation at about 400 C. for about 30 minutes, slitting, deposition of silver at a temperature of less than about C., and application of copper.

Reducing losses in SC cables

Microsoft Technology Licensing, LLC

October 22, 2019

U.S. Patent No. 10,453,592

Methods and apparatus are disclosed for cooling SC signal lines disposed on an interconnect such as a flexible cable or a rigid substrate. The SC signal lines are cooled to a cryogenic temperature lower than the temperature at which at least some SC logic devices coupled to the interconnect are operated. In some examples, an airtight conduit, heat pipe, or thermally conduct of strap provided to cool the SC interconnect. In one example, a system includes at least two sets of SC logic devices, cooling apparatus adapted to cool the logic devices to a first operating temperature, and interconnect coupling the SC logic devices, and a cooling apparatus in thermal communication with the interconnect. The apparatus is adapted to cool SC signal lines on the interconnect to a lower operating temperature than the first operating temperature at which the SC logic devices operate.

Systems and methods for fabricating SC integrated circuits

D-Wave Systems Inc.

October 22, 2019

U.S. Patent No. 10,453,894

Various techniques and apparatus permit fabrication of SC circuits and structures, for instance Josephson junctions, which may, for example be useful in quantum computers. For instance, a low magnetic flux noise trilayer structure may be fabricated having a dielectric structure or layer interposed between two elements or layers capable of superconducting. A SC via may directly overlie a Josephson junction. A structure, for instance a Josephson junction, may be carried on a planarized dielectric layer. A fin may be employed to remove heat from the structure. A via capable of superconducting may have a width that is less than about 1 micrometer. The structure may be coupled to a resistor, for example by vias and/or a strap connector.

Diode devices based on SC

PsiQuantum Corp.

October 22, 2019

U.S. Patent No. 10,454,014

An electronic device (e.g., a diode) is provided that includes a substrate and a patterned layer of SC material disposed over the substrate. The patterned layer forms a first electrode, a second electrode, and a loop coupling the first electrode with the second electrode by a first channel and a second channel. The first channel and the second channel have different minimum widths. The device further includes a magnet that applies a magnetic field to the loop, which produces an expulsion current in the loop that travels toward the second electrode in the first channel and toward the first electrode in the second channel. For a range of current magnitudes, when the magnetic field is applied to the patterned layer of SC material, the conductance from the first electrode to the second electrode is greater than the conductance from the second electrode to the first electrode.