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EUROTAPES Produces 600 meter-long REBCO HTS Tape

The EUROTAPES program has announced that it successfully achieved its major milestones as it draws to a close, including the production of an HTS coated conductor longer than 500 meters in length. EUROTAPES sought to integrate the latest developments in HTS tape evolution into simple conductor architectures for low- and medium-cost applications and deliver tapes over 500 meters long.

The program further aimed to use definition of quality control tools and protocols to enhance the processing throughput and yield to achieve a pre-commercial cost target of 100 €/kAm. Another key program goal was the creation of thicker, enhanced HTS tapes with higher I_c's, improved pinning, reduced AC losses, and increased mechanical strength.

Partners on the project included Bruker HTS, Nexans, LaFarga, Oxolutia, and six other research institutes and six universities. The EU covered the bulk of the EUROTAPES budget of €20 million ($21 million).

"The EUROTAPES project was completed on January 2017 following 54 Months of existence under the coordination of the Institut de Ciencia de Materials de Barcelona (ICMAB)," said Xavier Obradors, EUROTAPES Project Coordinator and Professor at ICMAB. "One of the objectives of the project was to demonstrate lengths in excess of 500 meters and this goal was achieved."

100 €/kAm at 77 K, Self-field Achievable with Existing Production Plants

Obradors described the progress on the EUROTAPES program's cost efficiency goals for HTS wire: "The project had specific technical objectives for three magnetic field-temperature regimes: 4.2 K at 18 T, 30 K at 3 T, and 77 K at self-field. The targeted costs considered for these three regimes were different because the application demands differ. The targeted 100 €/kAm corresponds to 77 K at self-field and is considered achievable with the existing production plants for large scale production. Different ranges of production costs are considered by the different industrial partners depending on the techniques used as well as the production volume.

"The project investigated essentially two routes to the coated conductor production: pulsed laser deposition (PLD) and chemical solution deposition (CSD), although inclined-substrate deposition (ISD) was also included.

YBCO-PLD tapes were produced by several partners and the industrial scaling was done by Bruker.

"YBCO-CSD was also produced by several partners and the industrial scaling was assumed by DNano and Oxolutia, while the ISD process was scaled up by Theva using GdBCO. All the conductors displayed improved performance after introducing specific nanostructures which were developed within the scope of the EUROTAPES project by the academic and industrial partners.

"Bruker was in charge of long-length production through PLD, and they used the technique to produce coated conductors in excess of 600 meters. The 600 meter-long coated conductor was a continuous production in the Bruker manufacturing unit. DNano, on the other hand, demonstrated over 100 meter-long coated conductors produced via CSD.

"The project produced different types of coated, flat conductors. These tapes, however, were also used within the consortium to develop a new concept of round wire: conductor-in-round-tube (CORT). This wire has a diameter of 5 mm and was fabricated by the Electrical Engineering Institute of Bratislava using DNano coated conductor."

600-m Coated Conductors have I_c of 130 A/cm-w at 77 K

Obradors noted that the current carrying capacity values differ between the tapes depending on the coated conductor length: "The over 600 meter-long coated conductors from Bruker have an I_c of 3.125 A/cm-w at 4.2 K and 5 T, 1.250 A/cm-w at 30 K and 5 T, and 130 A/cm-w at 77 K and self-field. In shorter lengths I_c values at 77 K and self-field reach as high as 1,000 A/cm-w have been demonstrated by Theva using ISD.

"Short lengths of DNano's coated conductors made via CSD displayed an I_c of 300 A/cm-w at 77 K and self-field. The range of J_c values at 77 K and self-field are usually between 2 and 4 MA/cm^2. The substrate thickness is usually 100 μm.

"The nanostructured coated conductors produced by Bruker display one of the worldwide highest performances under ultra-high magnetic field at 4.2 K. The tape achieved I_c values of 1,100 A/cm-w at 4.2 K and 18 T for a 600 meter-long tape. A 23 meter-long tape achieved 770 A/cm-w at 4.2 K and 31 T. The tapes produced in short

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lengths were also optimized through nanostructuration at other temperatures (30 K and 77 K) for both the PLD and CSD approaches."

Industrial Partners to Continue HTS Tape Development

Obradors said that with the conclusion of the EUROTAPES program, the members of the consortium would separately pursue development of their HTS coated conductors: "All the industrial and academic partners will follow plans to further develop their tapes for specific applications under internal development or via other European projects. Performance improvements are usually realized under collaborative projects with academic partners.

"Bruker, DNano, Theva, and Oxolutia continue to improve their manufacturing units and processes. There are also several projects funded by the EU and international or national funds to use the tapes in specific applications. Several EUROTAPES partners are involved in these projects.

"Wind generators, superconducting fault current limiters (SFCLs), and magnets are being pursued. Specific projects include FASTGRID for SFCL development; magnets and magnetic screens being developed via CERN; and the ECOSWING wind generator project."

In 2013, PerCoTech AG, a developer of HTS coated conductors based in Brunswick, Germany, announced that it was ceasing all R&D activity not related to the EUROTAPEAS project (see *Superconductor Week*, Vol 27, No 8). In 2012, Bruker Energy and Supercon Technologies, Inc.'s (BEST) Bruker HTS GmbH subsidiary received a €2.3 million ($3 million) grant from the European Commission's Directorate-General for Research and Innovation under the EUROTAPES project (see *Superconductor Week*, Vol 26, No 18). As the leading industrial partner for the project's scale-up efforts, Bruker HTS received the largest amount of funding from the program. ❍

AMSC to Conduct REG Deployment Study for Seattle City Light

AMSC has announced an agreement with the utility Seattle City Light to undertake a deployment study of the company's Resilient Electric Grid (REG) system. The study will focus on evaluating REG as a solution for a power distribution application within the utility's service area.

Seattle City Light serves more than 440,000 customers in the Seattle metropolitan area. The agreement for the study is a result of AMSC and Nexans' recent joint marketing agreement targeting the North American market for power distribution applications (see *Superconductor Week*, Vol 30, No 9).

AMSC Working on REG Deployment with Five Utilities

Seattle City Light is the fifth U.S. utility to enter into a REG deployment collaboration with AMSC. Work with ComEd in Chicago is the furthest advanced. The ComEd project has moved into its second phase, which encompasses the installation of a REG system into the electric grid.

AMSC is also carrying out deployment studies with Eversource Energy in Boston, PEPCO in the Washington, DC, and Pacific Gas & Electric (PG&E) in northern and central California. AMSC President and CEO Daniel McGahn has said in the past that the REG project design with PEPCO might turn out to be larger than the ComEd project.

AMSC recently announced that it has partnered with Black & Veatch, an engineering and energy infrastructure development company, on the PG&E project (see *Superconductor Week*, Vol 31, No 2). In addition to these five collaborations, McGahn noted during AMSC's most recent conference call that the company is tracking activity with over two-dozen U.S. utilities and has extended REG marketing efforts outside of North America to Australia and the UK.

Secondary Stock Offering to Finance Grid Activities

In support of its grid initiatives, AMSC has completed a $16 million public offering of common stock, consisting of 4 million shares at $4.00 per share. The underwriters have received a 30-day option to purchase up to 600,000 additional shares of common stock. At the time of its most recent quarterly earnings release, AMSC had 13.8 million diluted shares of common stock outstanding. ❍

NIST Developing SC Neuromorphic Computing System

Researchers with the National Institute of Standards and Technology (NIST) have proposed a hybrid semiconductor-superconductor hardware platform for the implementation of neural networks and large-scale neuromorphic computing. The platform combines semiconducting few-photon light-emitting diodes (LED) with superconducting-nanowire single-photon detectors (SNSPDs) to behave as spiking neurons. These processing units are connected via a network of optical waveguides, and variable weights of connection can be implemented using several approaches.

The system effectively mimics the architecture of the brain, which uses less energy than a light bulb to perform quadrillions of operations. The use of light as a signaling mechanism overcomes fanout and parasitic constraints on electrical signals while simultaneously introducing physical degrees of freedom which can be employed for computation. The use of supercurrents achieves a low power density at the 20-MHz firing rate, which is necessary to scale to systems with enormous entropy.

Limits to Transistor Miniaturization Encourage Neuromorphic Computing

"Starting at least as far back as the 1950s, people like John von Neumann were interested in understanding the brain as a computer and mimicking its behavior," said the NIST's Jeffrey Shainline, who works on developing the neuromorphic computing system. "The idea picked up steam again in the 1980s when Carver Mead proposed exploiting the analogous behavior of sub-threshold transistors to ion conduction channels in neurons.

"However, momentum didn't build in this community until recently due to the tremendous success of Moore's law. As long as making transistors smaller continued to deliver increased computational power, there wasn't much incentive to innovate at the architectural level. In the last five years or so, momentum has really been building in the neuromorphic computing community because transistors can't get much smaller, but architectural advances still have a lot to offer.

"There are challenges [to replacing electrons with photons as information carriers in a computing system]. For one, the wavelength of light puts a size limit on devices, so photonic devices tend to be larger than electronic devices. Ultimately for scaling of neuromorphic computers I think that this is the least important of the constraints, with energy efficiency and connectivity being far more important.

"That's why we argue that it is worth it to use photons to carry information. The energy efficiency and connectivity allow you to achieve computation on a scale otherwise unachievable, and the larger size is an inconvenience, not a fundamental obstacle. The more important challenge is integrating compact, efficient light sources on an integrated photonic chip."

Proposal Follows Demonstrations of Neuromorphic Principles

Shainline added that the current research builds on demonstrations of neuromorphic computing principles: “I was involved in some research a few years back wherein we worked within the constraints of a CMOS electronics process to create active integrated photonic devices which were driven by the electronics (doi.org/10.1364/OL.38.002657 & doi.org/10.1038/nature16454). The point of the work was to use a photonic interconnect to overcome the bandwidth and energy limitations of a traditional copper interconnect.

“We were able to demonstrate a system that booted Linux and ran a memory-intensive application using only optical communication between the processor and memory. The point of that work was to show that using light for connectivity was feasible, advantageous, and that it could be done with zero changes to the foundry process, thereby making the concept economically feasible.

“The challenge that remains has to do with the light sources. Silicon is an indirect-gap semiconductor, so it is inefficient at emitting light, even when clever heterostructures are grown. So integrating better light emitters (almost always III-V materials) directly on silicon or coupling the light from III-V lasers via optical fibers into silicon waveguides are the preferred approaches.

“Unfortunately, this tends to be difficult and expensive. Great progress is being made, but getting good light sources coupled to the silicon photonics is a major challenge for the field. A related challenge is getting good detectors integrated with silicon waveguides. There are solutions here, but none have high internal quantum efficiency with low dark-state power consumption.”

SC Optoelectronics Ideal Detector Technology

Shainline said that superconducting optoelectronics offer a detector technology well-suited for neuromorphic computing: “Once one recognizes the advantages of implementing fanout and routing with photonics, one must then decide which light sources and detectors to use. Our group has extensive experience in using superconductors to detect single photons, and these superconducting detectors are ideal for this application.

“They allow detection of optical signals down to single photons, and because they superconduct they can, in principle, draw no power in the dark state. These two traits taken together enable the lowest power consumption of any optical detector. Having decided to use superconductors to detect the optical signals, we knew our system would operate at around 4 K, [and that] silicon [would no longer be] inefficient at emitting light.

“It turns out that local imperfections in the silicon lattice (point defects) can place optically active states within the band gap, so one can engineer LEDs based on these atom-like emitters directly in silicon, and they’re reasonably efficient. All the calculations in our recent paper assume an LED with 1% efficiency, which should be possible with these emitters.

“Further, they’re extremely easy to make with conventional silicon processing, so scaling up to systems of billions of them is entirely feasible. In fact, we recently demonstrated these silicon LEDs connected to WSi superconducting single-photon detectors via nanophotonic waveguides.

“The integration of light sources with detectors is generally the hardest part of using light as an information carrier, yet the superconducting optoelectronic platform looks promising because working at low temperature provides enticing new options for silicon light sources. [In addition], working with superconducting detectors means the light sources don’t need to be bright or coherent.”

Photons Avoid Constraints Inherent to Electrons

Shainline said that communication with

photons would avoid many of the constraints inherent in electrons: “Electrons are charged particles which repel one another. If I put one on a plate, it takes slightly more energy to put the next one on there. This leads to the phenomenon of capacitance, and all electrical systems experience parasitics, usually due to capacitance, but also due to inductance and resistance in non-superconducting systems.

“These parasitics are fundamental to the physics of electrons and their coupling to the electromagnetic field. If one wishes to connect one neuron to many other neurons, extensive wiring is required, and all these wires have some combination of capacitance, inductance, and resistance. This means that as I add more connections, the speed at which I can send signals over those wires gets reduced, and the energy required to send those signals increases.

“This puts a limit on how many electronic neurons can be directly connected to each other. To overcome this, the neuromorphic computing community has come up with ways to reduce the number of wires in a system by sharing wires.

“Signals over these wires must then be staggered in time to avoid cross talk on the shared communication lines. This approach is called time-multiplexing. It is promising as a means to make useful systems in spite of these parasitic limitations, but it is still limiting in important ways, which is what drove us to consider the use of light instead.

“With light, the problem of parasitics goes away. Photons are uncharged bosons, so they don’t interact with each other. If there is a photon in a waveguide, another one has no problem passing right through it without interacting. This removes the fundamental limitation on how many connections can be made between neurons, and replaces it with the more practical limitation alluded to above related to the size of massively connected neurons.

“Still, we calculate that we can implement networks with neurons each having 700 independent connections to other neurons in a compact manner. We can even go to 10,000 connections per neuron, like the human brain, but the systems get a little big. We expect architectures to emerge in which 700 connections is standard, and specialized neurons with 10,000 connections are present but sparse.

“Related to the non-parasitic nature of light is the fact that we can implement waveguide crossings, enabling dense routing with a minimal number of layers in the process, as is described in a separate study (doi.org/10.1364/OL.39.000335). And further, we’ve recently been developing deposited waveguide technology so we can implement fanout and routing with 3D waveguide networks.

“In an upcoming study (arXiv:1611.0234), we demonstrate the proof of concept with one layer, but we are presently fabricating three-layer systems. The ultimate goal is fanout and routing with ~10 layers of waveguides.”

NIST Team Working on Fabrication Process

Shainline touched on the challenges to developing a prototype system: “There is a lot of uncharted territory here, so we’re trying to develop new light sources and scale up detector technology. In CMOS, if someone wanted to investigate new types of devices, they would just lay them out and a foundry would fabricate them.

“In this case, no foundry in the world has a process to fabricate these systems yet, so we have to get in the cleanroom and make them ourselves. We’re currently building up this fabrication process one step at a time. We’re also preparing to add Josephson junctions to our process.

“There are also significant measurement challenges. We’re making devices that produce single photons and convert them to very small electrical signals.

"The metrology infrastructure for these kinds of measurements is really in its infancy, so we're building a lot of that right now. It all happens at 4 K, so you have to get optical and electrical signals into and out of a cryostat."

System could Employ Extensive SC Architecture

Shainline expanded on the extent to which a neuromorphic system might incorporate superconducting components: "We envision very complex systems employing entire superconducting electronic systems integrated with the optoelectronic devices. Josephson circuitry will bias all the detectors and distribute current dynamically based on activity in the network.

"Further, neuromorphic circuits based on single-flux quantum pulses are being developed, and they offer extraordinary promise in terms of speed and energy efficiency. They still suffer from the parasitics of electronics described above, but their speed and efficiency makes them very appealing. We envision hierarchical neuromorphic computers employing neuromorphic Josephson junction circuits interacting with neuromorphic optoelectronic circuits.

"In the human brain there are 10^{11} neurons. The subtleties of the brain's computing power remain elusive, but it is assumed that advanced phenomena such as creative thinking and consciousness require a comparably large number of computing elements. In order for a system to contain this many operational components and not require a dedicated nuclear reactor, energy efficiency is paramount.

"Additionally, even if one were willing to dedicate a nuclear reactor to the system, if the power density is too high it will be impossible to cool the system. The devices will be unable to operate reliably, and the chip may even melt. It is this power density of copper interconnects that ultimately limits their scaling and has driven some in the community to pursue photonic interconnects."

Power Demands of Cooling Offset by Power Density

Estimates comparing the proposed hardware platform to a human brain show that with the same number of neurons and 700 independent connections per neuron, the hardware could achieve an order of magnitude improvement in synaptic events per second per watt. This means in effect that the system could perform more operations using less energy than the human brain.

"The requirement of keeping the system cold places a fundamental limit due to the Carnot efficiency of something like an extra factor of 100 on the device power consumption," said Shainline. "Still, if one works out the numbers, for large scale systems one still comes out ahead. The dual advantages of superconducting optoelectronics, few-photon signals and no steady-state power consumption, are very compelling.

"Further, while the cooling power affects the total power consumed by the system, it doesn't affect the power density, which is usually what limits scaling. Our calculations show that we can reach the number of neurons in the human brain in a system with 20 kW total power consumption, meaning device and cooling power. This looks to me like it would be a tremendously powerful technology, and in comparison to the roughly 20 MW of a modern-day supercomputer, the system power should not be a significant deterrent.

"Having said that, you're never going to put a superconducting optoelectronic circuit in a cell phone. Thus, many devices will have electronic neuromorphic chips locally, and they'll communicate to the more powerful superconducting optoelectronic neuromorphic systems inside cryostats with wireless communication. That's my prediction.

"My full-time job [is the development of a prototype neuromorphic computing system]. I have given up all my other projects, and I'm completely focused on this. We recently demonstrated coupling of the emitter to the detector via a nanophotonic waveguide, and we're planning our next steps to fabricate superconducting optoelectronic neurons." ❍

OST Acquisition Boosts BEST Revenues

Bruker Corporation announced revenues of $384.9 million for Q1 FY2017, 2.5% higher than Q1 FY2016 revenues of $375.4 million. Excluding a 5.3% positive effect from acquisitions and a 2% negative effect from changes in foreign currency rates, the company reported a year-over-year organic revenue decline of 0.8% for the period.

Non-GAAP net income for the quarter fell by 12.8% to $29.9 million from $34.3 million in the year-ago quarter. Bruker's share price rose by 2.1%, from $24.91 to $25.43, on the day following the earnings announcement.

"We again improved our gross and operating margins year-over-year," commented Frank Laukien, Bruker's President and CEO, in the earnings conference call. "Q1 FY2016 was a challenging comparison, which included revenues from a high-margin 1 GHz NMR system (see *Superconductor Week*, Vol 30, No 4), a major Bruker detection contract, and an unusually low tax rate."

BEST Revenues 47.4% Higher

The Bruker Energy & Supercon Technologies (BEST) segment increased revenues by 47.4%, from $27.2 million in Q1 FY2016 to $40.1 million in Q1 FY2017. BEST's system and wire revenue, which includes LTS and HTS wire and superconducting devices including magnets, linear accelerators, and radio frequency cavities, rose by 48.5% from $26.4 million in Q1 FY2017 to $39.2 million.

The segment incurred an operating loss of $0.5 million in Q1 FY2017 compared to breakeven over the comparable period the previous year. The revenue increase and operating loss resulted primarily from the Oxford Instruments Superconducting Wire LLC (OST) acquisition that was completed in Q4 FY2016 (see *Superconductor Week*, Vol 30, No 11).

"BEST had an improved Q1, as demand for superconducting materials and the strong order book of 2016 continued to drive the segment's results," Laukien noted. "Our newly acquired Bruker-OST unit in New Jersey had revenues and margins slightly ahead of expectations, given good demand for Bruker-OST's proprietary rod reset process (RRP) high magnetic field wire technology."

NMR Sales Propel BIOSPIN

BIOSPIN Group delivered low single-digit revenue growth, as solid NMR results more than offset preclinical imaging revenue. The group continued to show strong margin gains and was a major contributor to Bruker's growth and operating margin expansion.

"NMR, not unlike some other parts of our business, has seen continued strength in Chinese academic spending," Laukien said. "We expect to have revenue from a 1 GHz NMR system this year. If that happens, it would be in Q4, but due to its complexity and timing, it could also shift into 2018."

For FY2017, Bruker is maintaining its organic revenue growth, non-GAAP operating margin expansion, and non-GAAP EPS outlook. However, the company is adjusting its reported revenue growth outlook to reflect recent changes in foreign currency translation rates and expects revenue growth of 2 to 3.5%. This would consist of organic revenue growth of 1 to 2%, and growth from acquisitions of 3.5 to 4%. ❍

STI Preparing for Commercial Wire Production

Superconductor Technologies Inc. (STI) announced in its Q1 FY2017 earnings report that in March the company began shipments of Conductus HTS wire to key customers. The shipped Conductus wire incorporated the combined improvements in both mechanical and critical current capacity performance that had been achieved earlier this year (see *Superconductor Week*, Vol 31, No 3). STI is currently focusing efforts on preparing for the commercial production of Conductus wire.

"We've got the wire in the hands of four or five customers right now who are doing qualification testing," commented STI President and CEO Jeff Quiram during the earnings conference call. "The one that has the largest near-term potential demand is a fault current limiter customer."

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): "We anticipate work on our project should begin Q3. Under the NGEM program, we will further evaluate several techniques that we believe will greatly improve the performance of Conductus wire while reducing the overall manufacturing costs."

Funds for Operations through Q1 FY2018

For Q1 FY2017, STI reported net revenues of $1,000, a 98.9% decline from Q1 FY2016 revenues of $89,000. The revenues were primarily realized from legacy wireless products.

The quarterly net loss of $2.5 million was about the same as the Q1 FY 2016 loss. The company's share price fell by 11.2%, from $2.05 to $1.82, on the day of the earnings announcement.

STI held $8.4 million in cash on its balance sheet at the end of Q1 FY2017 compared to $10.5 million at the end of Q4 FY2016. Subsequent to the end of the quarter, the company received $200,000 from the exercise of warrants. In the conference call, CFO Bill Buchanan stated that existing cash resources would be sufficient to fund planned operations through the Q1 FY2018. ❍

TU Delft Integrates Microwave Laser onto Quantum Chip

A team of researchers from the Delft University of Technology (TU Delft) in the Netherlands has demonstrated an on-chip microwave laser based on a fundamental property of superconductivity, the AC Josephson effect. The research is part of ongoing efforts to develop microwave lasers that will not disturb the cryogenic environment in which quantum technology operates. The research was not directly funded but partial funding for the theoretical work was paid for by an ERC synergy grant, from the Dutch government's FOM program Netherlands Organisation for Scientific Research (NWO/OCW), and Microsoft Station Q.

The Josephson effect suggests that if a very short barrier interrupts a piece of superconductor, the electrical carriers tunnel through this non-superconducting material by the laws of quantum mechanics. The electrical carriers do this at a characteristic frequency which can be varied by an externally applied DC voltage. The Josephson junction therefore serves as a voltage-to-light frequency converter.

"The key challenges [to integrating a microwave laser onto a quantum computing chip] are reaching a strong enough coupling regime, keeping the emitter frequency stable so that a coherent state can be built up inside the cavity, and minimizing losses in the cavity," said Maja Cassidy, currently a Research Fellow at the University of Sydney but a Postdoctoral Fellow at TU Delft at the time of the research. "Our group are experts in making extremely high quality factor superconducting cavities, in excess of 10^6, which we utilized in this invention to minimize losses in the cavity.

"To keep the emitter frequency stable, we used a low temperature biasing circuit to provide a stable voltage bias. The increased coupling strength was achieved by attaching the Josephson junction directly to the cavity.

"[In terms of improvements to the current design], the linewidth needs to be further improved. We would also like to demonstrate pulsed operation."

Circuit Entirely Superconducting

The researchers embedded a small section of a superconducting Josephson junction in an on-chip cavity. The device opens the door to applications in which microwave radiation with minimal dissipation is key, for example in controlling qubits in a scalable quantum computer.

Lasers are capable of emitting perfectly synchronized, coherent light, which means that their linewidth is very narrow. Typically lasers are made from a large number of emitters inside a cavity, but such conventional lasers are inefficient and dissipate heat while operational. Such heat dissipation is detrimental in cryogenic enviornments.

"The circuit is entirely superconducting, and so it has very little intrinsic losses," added Cassidy. "Therefore most photons emitted by the junction can be transferred to the output."

Team Plans to Test Chip for Qubit Control

The device fabricated by the Delft team is made from a single nanoscale Josephson junction strongly coupled to a 5-mm long, high quality factor superconducting NbTiN microcavity. When a small DC voltage is applied across the junction by a battery, the difference in energy causes microwaves to be released when a Cooper pair tunnels across the junction.

The cavity then provides amplification, causing a beam of coherent microwave light to be emitted from the cavity. These microwave bursts can be used to read out and transfer information, correct errors and access, and control the individual quantum components within a quantum computing system.

"This was the first designed chip we made," said Cassidy. "Testing the chip for qubit control will be one of our first follow up experiments."

Circuit Design to be Extended for Electrostatic Gating

Because the on-chip laser is made entirely from superconductors, it is more stable than previously demonstrated semiconductor-based lasers. It also uses less than a picoWatt of power to run.

"The superconducting laser doesn't suffer from charge noise, which would cause the emitter to emit off resonance and the laser to lose phase coherence," said Cassidy. "For some applications, the linewidth [in our current circuit] may be sufficient, however we believe we can improve it further."

The group is extending their design to use tunable Josephson junctions made from nanowires to allow for microwave bursts that enable fast control of multiple quantum components. Such a device may be able to generate so-called amplitude-squeezed light, which has smaller intensity fluctuations compared to conventional lasers. This is important for quantum communication protocols.

"Nanowires can be gated electrostatically which means that the laser can be turned off and on very fast," said Cassidy. "We are currently preparing our results for publication." ❍

Research Team Studies SC in Ultrathin Crystalline Al Films

Researchers with Louisiana State University (LSU), the University of Texas at Austin (UT Austin), and Forschungszentrum Jülich have completed a study of the Zeeman-mediated superconducting phase diagram in ultrathin crystalline aluminum films (doi.org/10.1103/PhysRevB.95.094520). The UT Austin group was funded by the National Science Foundation (NSF) and the Office of Naval Research in support of the film synthesis and characterization. The LSU group is funded by the DOE's Basic Energy Sciences division for the low temperature measurements of the film's superconducting properties.

The researchers conducted parallel critical field measurements down to 50 mK across the superconducting tricritical point of films ranging in thickness from 7 to 30 ML. The resulting phase boundaries were compared with the quasiclassical theory of a Zeeman-mediated transition between a homogeneous BCS condensate and a spin-polarized Fermi liquid.

Phase Diagram of Al Thin Films not in Agreement with BCS

Films thicker than 20 ML showed good agreement with theory, but thinner films exhibited an anomalous phase diagram that cannot be reconciled within a homogeneous BCS framework. Philip Adams, Professor at LSU and co-author of the study, said that it is not yet known why films thinner than 20 ML do not agree with the BCS framework: "The system simply cannot reach the limits of instability that the theory predicts. We believe this may be caused by the emergence of a disordered FFLO phase.

"In our experiments we drive the films from the superconducting phase to the normal phase via the Zeeman splitting of the conduction electrons. However, unless the films are extremely thin orbital effects will preempt the Zeeman-mediated phase transition, even if the field is applied parallel to the film surface.

"One of the primary strategies for getting very thin, ~2 to 3 nm films is to evaporate them onto a cryogenic substrate. This limits the diffusion and helps prevent the film material, in our case aluminum, from forming islands.

"Indeed, this technique has been used in all previous studies of Zeeman-limited superconductivity in aluminum and beryllum films over the last 40 years. So, when [UT Austin Professor] Ken Shih approached us with the possibility of studying the transition in crystalline Al films that his group was producing, we saw an opportunity to study the transition in an almost ideal system.

"Previous studies of the transition in highly disordered, quench-condensed aluminum films revealed a number of effects that could not be easily accounted for via BCS theory. These include avalanches, stretched-exponenial relaxations, and enhanced T_c relative to the bulk. It was thus difficult to sort out what behavior was intrinsic to a generic BCS superconductor and what was a manifestation of disorder.

"Naively, we expected that the crystalline films would exhibit a phase diagram that would be in good agreement with what was predicted by the extended BCS theory. However, this was not the case, particularly in the thinnest films we studied.

"Although the avalanched behavior we had previously reported in highly disordered aluminum films was no longer evident, we found that the hysteresis widths in the first-order region were much too narrow. This was primarily due to the fact that the supercooling branch was at too high of a field compared with theory."

New Phase may be FFLO Remnant

Adams also commented on the implications of the study's results: "The most important implication is that a new phase emerges near the

Zeeman critical field that preempts the expected homogeneous BCS superconducting phase. We believe it is a disordered remnant of a FFLO phase. In many respects, FFLO is the original non-conventional superconducting state.

"It was predicted in the 1960s. Unfortunately, it is exquisitely sensitive to disorder, but nonetheless we believe we see manifestations of its remnants in our crystalline aluminum films. I should note that although the crystalline films are much less disordered than their quench-condensed counterparts, they are still much too disordered to support a true FFLO phase having long range order.

"Up to this point we have only studied the transport properties of the crystalline films. Our next goal is to use the tunneling density of states to probe the condensate in the critical region. We are also planning to study the proximity effect in this Zeeman-limited regime." ❍

Penn State's Liu Describes Unconventional SC in 2D TMDs

A researcher with Pennsylvania State University has suggested the existance a rich phase diagram for unconventional superconductivity in 2D transition metal dichalcogenides (TMDs) (doi.org/10.1103/PhysRevLett.118.087001). The predicted phase diagram for 2D TMDs includes intralayer and interlayer singlet pairings and interlayer triplet pairings.

SC Behaves Differently in 2D, Bulk TMD Materials

"Superconductivity has been known in TMD materials for quite a long time," said Chao-Xing Liu, Assistant Professor at Penn State and author of the paper. "The recent development is to make these superconducting TMD materials atomically thin.

"TMD materials are a new members of the 2D family of materials, and it is interesting that some 2D TMD materials, such as $NbSe_2$ and MoS_2, can also be superconducting. Superconductivity in bulk TMD materials, also including $NbSe_2$, is of the conventional s-wave spin singlet type. However, when these TMD superconductors become atomically thin, an intriguing Ising superconductivity emerges due to the strong spin-orbit coupling in these systems.

"Compared to iron chalcogenide superconductors, in which unconventional superconductivity is induced by strong interaction, superconductivity in atomically-thin TMD materials still originates from electron-phonon interaction as described in standard BCS theory. The unconventional part of TMD superconductivity comes purely from the unique strong spin-orbit coupling."

Team Predicts FFLO State

Liu added that he expects that the superconductivity in TMDs could exhibit a number of unusual traits: "The combination of spin-valley-layer degrees of freedom and a crystal structure that is globally centrosymmetric but locally non-centrosymmetric in TMDs suggests interesting unconventional superconductivity can lead to an interesting phase diagram with different types of unconventional pairings in bilayer TMD superconductors. We predict a FFLO superconducting state under an in-plane magnetic field in bilayer TMD superconductors.

"The Cooper pairs in a FFLO state can carry a finite momentum, in contrast to the usual BCS state in which the Cooper pairs carry zero total momentum. Given the fact that superconductivity has been observed in $NbSe_2$, multi-layer $NbSe_2$ superconductors should be a good candidate in the search for FFLO states in TMD superconductors.

"A spin-triplet component exists in Ising superconductivity, making it possible for this type of superconductivity to penetrate into ferromagnetic materials. A recent proposal (Phys. Rev. B 93, 180501 (2016)) suggests that combining a half-metal wire or a special type of ferromagnetic wire and $NbSe_2$ films can lead to topological superconductivity with Majorana zero modes at the end of the half-metal wire.

"Majorana zero modes obey non-Abelian statistics and could potentially be used as qubits to store and process information in a new computation architecture called topological quantum computation (TQC). TQC is expected to be immune from decoherence caused by local environments."

Monolayer $NbSe_2$ has H_{c2} of 30 T

Liu said that 2D TMDs such as $NbSe_2$ exhibited a high upper critical field (H_{c2}): "In experiments, the H_{c2} of mono-layer $NbSe_2$ can be more than 30 T, while that for bilayer and trilayer $NbSe_2$ can also exceed 18 T. In monolayer $NbSe_2$, this high Hc_2 can be fully explained by Ising superconductivity, which greatly reduces the influence of the spin Zeeman effect of magnetic fields.

"For multi-layer $NbSe_2$, Ising superconductivity is not enough to explain this high H_{c2} because the orbital effect of the magnetic field is also important. Our work provides a possible explanation to resolve this issue." ❍

Aalto Creates a Quantum Circuit Refrigerator

Researchers at Aalto University's Quantum Computing and Devices (QCD) Lab have developed a nanoscale refrigerator that can cool a quantum computing circuit (doi:10.1038/ncomms15189). Their system, called a quantum circuit refrigerator, has the potential to increase quantum computing efficiency and reliability. The work received funding through a €1.9 million ($2.1 million), five-year European Research Council (ERC) Consolidator Grant, as well as from the Academy of Finland, the Emil Aaltonen Foundation, the Jenny and Antti Wihuri Foundation, and the Finnish Cultural Foundation.

"The main objective of the ERC Consolidator Grant is to build coolers for qubits and to study how qubit dynamics are affected by the tunable environment," commented Aalto Professor Mikko Möttönen. "I think that there is great potential in integrating the refrigerator in superconducting quantum devices.

"For some, of course, it would couple less strongly than for others. When we did the math, and it turned out that the refrigerator couples roughly ten times stronger to a usual superconducting qubit than to the resonator we used in the experiments. Of course, we can always make the coupling weaker via a shunting circuit."

Circuit Cooled with Photon-assisted Electron Tunneling

Because of their very low tolerance towards environmental disturbances, qubits must be well isolated from all sources of dissipation during a quantum coherent operation. However, the isolation of qubits also typically creates elevated operation temperatures and long natural initialization times, necessitating a means of keeping quantum systems cool.

The Aalto team utilized photon-assisted electron tunneling to cool a prototype superconducting quantum circuit in the form of a transmission line resonator. The tunneling was undertaken in normal metal-insulator-superconductor (NIS) tunnel junctions, using copper as the normal metal and aluminium as the superconductor. The NIS junctions were coupled to the fundamental resonator mode through voltage.

"We first considered a completely different experiment to study the heat conduction between the two normal-metal resistors through the resonator photons," Möttönen said. "When we conducted the experiments, we saw that the probe resistor cooled down even when the refrigerator resistor, which we operated with bias voltage, heated up. We knew that this could not be explained through heat conduction alone.

"The effective temperature towards which the refrigerator drives the quantum system ranges from about half of the electron temperature to very high temperatures. These high temperatures appear at high bias voltages - much higher than the superconducting gap.

"However, in our current experiments we experienced a lot of heat leakage to the resonator. Because of this we could not cool the resonator to [extreme] low temperatures. It stayed somewhat above 300 mK at its lowest, with the starting resonator temperature at ~800 mK."

Cooling Adjusted through External Voltage Source

The researchers used an external voltage source to give the electrons passing through the NIS slightly less than the necessary energy for direct tunneling. The electron then captured the missing energy from the nearby quantum device, which lost energy and cooled down.

The cooling could be switched off by adjusting the external voltage to zero. The available energy would then not be sufficient to push the electron through the insulator.

"We had a voltage source at room temperature and could change the output voltage of this source," Möttönen noted. "When we didn't apply any bias voltage, the electron tunnelling was exponentially suppressed because even if the electrons absorbed a photon from the resonator, it would be much less than the gap energy needed to tunnel into the superconductor. If we increased the bias voltage, that energy added up to the photon energy and at some point tunnelling became relatively frequent."

Team Plans to Lower Minimum Temperature

The group plans to build on their findings by cooling actual qubits in addition to the resonator. They will also seek to lower the minimum temperature achievable with the refrigerator and to increase the speed of the on/off switch.

"If we can get the qubits colder, we can initialize them more accurately in the ground state," Möttönen explained. "The excited state population decreases exponentially with decreasing temperature, so even halving the qubit temperature is a big deal."

Möttönen's team is one of ten research groups that has applied for funding for a new Academy of Finland Center of Excellence on Quantum Technology. The research will be pursued further under one of the Center's focus areas, which will cover open quantum systems and control of dissipation and be lead by Professor Jukka Pekola. ❍

Ames Study of A_eA1144 Sheds Light on Fe-based SC

Researchers at the U.S. DOE's Ames Lab have created and studied a pure, single-crystal sample of a new iron arsenic superconductor, $CaKFe_4As_4$. The compound is the first bulk iron-based material to become superconducting without doping, enabling research into HTS in iron pnictides without the disorder introduced by dopants.

Scientists from Iowa State University (ISU) and Ruhr University Bochum also participated in the research. The study received financial support from the DOE Office of Science, Basic Energy Sciences, Materials Science and Engineering Division.

"Unlike cuprates and MgB_2, iron pnictides are malleable, which means it is relatively easy to form wires and contacts," commented Ames Lab Researcher and ISU Professor Adam Kaminski. "This family is particularly interesting as it has maximum T_c without any dopants. This is important for both applications and the study of the superconducting mechanism."

HTS Mechanism for Iron Pnictides in Dispute

The superconducting mechanism in iron-based HTS has been a topic of debate in condensed matter physics. A key question has been whether this mechanism involves weak BCS-type coupling with interband repulsion between electron and hole bands playing a key role or a strong coupling with strong short-range antiferromagetic fluctuations. Weak coupling seemed consistent with experimental results from a number of iron pnictide superconductors, but was later thrown into question by the discovery of iron chalcogenide superconductors.

A new iron-based class of superconductors has recently been identified: $A_eAFe_4As_4$ or A_eA1144, where A_e = Ca, Sr, or Eu and A = K, Rb, or Cs. These share the chemical composition of the well-studied (Ba, K)Fe_2As_2 superconductors, but have a different crystal structural type, with the A_e and A layers alternatively stacked between the Fe_2As_2 layers. The material also features different length As-Fe bonds, which has been proposed as important parameters controlling T_c.

The research team grew the $CaKFe_4As_4$ single crystals using the flux method. They used high resolution angle resolved photoemission spectroscopy (ARPES) and density functional theory to measure the electronic structure and values of the superconducting gap of the material and found that it had a nearly optimal T_c of 35 K without doping or substitution.

Studying the compound without the interference of dopants, their results contradicted the simplified version of the antiferromagnetic fluctuation model. Instead, their findings support the multiband character of the superconducting gap in which Cooper pairs form the electron and hole bands with interband repulsive interaction.

Kaminski noted that the results did not directly address whether different lengths of As-Fe bonds have an impact on T_c: "However, there is a large body of evidence that this is correct. Band structure and superconductivity in pnictides are very sensitive to ionic positions and length of bonds.

"We are studying the effects of dopants and how they affect superconductivity and band structure. This will allow us to know whether this material is a special case or if it fits within a broader, current understanding of pnictides." ❍

Superconductivity Roundup

Events & Opportunities from Around the Industry

SW A research team from **ETH Zurich** has **simulated a 45-qubit circuit** using the Cori II supercomputer at Lawrence Berkeley National Lab. The simulation represents the largest simulation of a qubit-based system to date. The Cori II supercomputer has a peak performance of 29.1 petaflops and 1 PB of aggregate memory. The simulations of low-depth random quantum circuits were originally proposed by Google as a demonstration of quantum supremacy.

The ETH Zurich team plans to add more qubits to their simulation. Although 49-qubits is widely-held as the point at which quantum devices surpass the most capable traditional supercomputers and thwart larger simulations, the researchers plan to reach this threshold.

sw **Market.biz** has released the "**Superconducting Wire Market 2017**" research report in which it offers an analysis of the superconducting wire market from 2017 to 2022. The report includes an analysis of a number of key vendors including American Superconductor Corporation, Bruker Corporation, Fujikura Ltd., Furukawa Electric Co., Ltd., Superconductor Technologies Inc., Japan Superconductor Technology, Inc., Sumitomo Electric Industries, Ltd., Supercon Inc., Superox, and Theva Dunnschichttechnik GmbH.

sw **China** has **completed** a 10-year program through which it supplied its share of the **superconducting strand** for the **ITER fusion reactor**'s magnet systems. Chinese industry has produced approximately 65% of the NbTi strand needed for ITER's poloidal field coils and 7.5% of the Nb_3Sn strand needed for its toroidal field coils. Manufacturing the strand to ITER's quality specifications required detailed R&D and qualification phases, as well as close cooperation with the ITER Organization and other strand suppliers.

The last batch of NbTi strand left the Chinese manufacturing facility in March. Nb_3Sn strand production was completed in 2015. A ceremony was held to celebrate the completion of the program at the facility of strand supplier Western Superconducting Technologies (WST).

sw **ITER** separately announced that the first 110-ton **winding pack** produced in Europe for the toroidal field magnet system is **ready to be transferred** to contractor **SIMIC**. Each winding pack, or central core, is formed from seven stacked double pancakes of Nb_3Sn superconductor wound into a D-shape, inserted into mechanical support structures called radial plates, and insulated. The resin impregnation of the full stacked assembly was one of the final steps performed in La Spezia, Italy, in order to electrically insulate the component and create a rigid assembly.

Dozens of companies have participated in the qualification and production of the winding pack. These including the ICAS consortium composed of ENEA, Tratos Cavi, and Criotec; the ASG consortium composed of ASG Superconductors, Iberdrola Ingeneria, and Elytt Energy; French company CNIM; and the Italian firm SIMIC, which will conduct cold testing and insertion into steel cases.

The European Domestic Agency for ITER is responsible for the procurement of nine toroidal field coils plus one spare. The Japanese Domestic Agency, which is responsible for nine others, also recently produced its first winding pack. The first 17-meter tall, 310-ton completed toroidal field coil, composed of the winding pack and a steel case, will be shipped to the ITER site in 2018.

sw **Microsoft** has reportedly been working with **Rambus, Inc.** on the development of **quantum computing technology**. Rambus is known for the development of RDRAM and computer memory systems. The collaboration, begun in 2015, is focused on the development of a prototype quantum computing system with memory subsystems that can be cooled at cryogenic temperatures.

Cryogenic memory has been proposed as a possible replacement for existing memory technologies like DDR DRAM. It's becoming hard to make smaller memory chips with more capacity using current technologies.

As servers are being loaded with more memory to run applications like machine learning and analytics, a small box of cryogenic memory could replace large arrays of DRAM. Cryogenic memory blocks may also be faster and more efficient at cooler temperatures in data centers.

While Microsoft is interested in cryogenic memory, the quantum technology being pursued by the company does not incorporate superconducting Josephson junctions. Instead, Microsoft's quantum computing system is based on a new topology, exotic materials, and an as-of-yet undiscovered particle, and as such it could be years or even decades before it is released.

sw **The Market Reports** has released the "**Global Superconducting Fault Current Limiter (SFCL) Industry Market Research 2017**" research report in which it forecasts the SFCL market through 2022. The report includes details regarding production, revenue, gross margin, consumption value and volume, sale price, and import and export values.

sw **Florida State University**'s (FSU) **Applied Superconductivity Center** (ASC) has hired **Lance Cooley**, formerly with the Fermi National Accelerator Lab (Fermilab). ASC is based at the FSU's National High Magnetic Field Lab (MagLab).

Cooley worked on superconducting materials as a graduate student at the University of Wisconsin (UW) under David Larbalestier, receiving his doctoral degree in 1993. Larbalestier is currently Chief Materials Scientist at ASC. Cooley has held positions at National Institute of Standards and Technology, UW, and Brookhaven National Lab.

During his time at Fermilab, Cooley coordinated multiuniversity research to understand the effects of metalworking and chemical polishing on the superconducting properties of high-purity niobium used in linear accelerators. FSU was a participant in the program.

At FSU, he will work primarily to help expand research opportunities in areas where scientists have not commonly used superconducting magnets or materials. For example, he will explore how superconducting coils could be used at lower fields and warmer temperatures than MagLab's systems to power offshore wind turbines and how to enable the use of high-power electron beams for industry by making the accelerator part compact and superconducting. Cooley will join FSU in August.

sw **AMSC** has announced that **Electrical Consultants, Inc.** (ECI) of Billings, MT, is now a **certified installer** of AMSC's superconducting **Resilient Electric Grid** (REG) solutions in the U.S. The announcement is an expansion to AMSC's existing strategic relationship in which ECI performed engineering, procurement, and construction (EPC) services to over a dozen projects with AMSC's grid products. ECI is a transmission & distribution (T&D) consulting design firm and one of the largest specialty EPC companies in the U.S.

As AMSC accepts REG projects as prime contractor to U.S. utilities, having proven EPC capabilities should facilitate smooth construction and installation of the REG product. ECI further enables AMSC to offer REG solutions to a potentially broader customer base and establishes additional channels to market in North America.

Aspects of projects that are expected to be supported by ECI include substation construction and modifications as well as installation of cable duct and ancillary equipment, including cooling systems, in addition to related engineering. AMSC and ECI's relationship is non-exclusive and AMSC continues to work to qualify other EPC companies as certified installers of REG solutions in order to offer the market multiple approaches.

sw **Mevion Medical Systems** has entered a strategic agreement with **medPhoton GmbH** to integrate **ImagingRing**, a cone beam computed tomography (CBCT) system for volumetric image guidance, with the **MEVION S250i** with HYPERSCAN, Mevion's superconducting pencil-beam scanning proton therapy system. Mevion markets the MEVION S250 as the most compact proton therapy system on the market.

CBCT imaging helps to precisely position patients for pencil beam proton therapy. In-room CBCT will enable users to treat patients with image guided radiation therapy (IGRT) technology and deliver high-precision positioning and adaptive proton therapy.

Superconductor Week
Commercialization · Markets · Products
Business Developments · R&D · Cryogenics
~Insert~
May 31, 2017 Vol. 31, No. 4

U.S. Superconductivity Patents

SC Coil Device with Switchable Conductor
SIEMENS AKTIENGESELLSCHAFT
Dec. 27, 2016
U.S. Patent No. 9530549
In a coil device with at least one electrical coil winding with SC conductor material, the coil winding is part of a self-contained circuit for formation of a continuous current. The closed circuit has a switchable conductor section which can be switched between a SC state and a normally conducting state by a magnetic device.

Monitoring the Integrity of a Pipeline
Eni S.p.A.
Jan. 3, 2017
U.S. Patent No. 9535037
An inspection apparatus for monitoring the structural integrity of a pipeline comprising a SC electromagnet suitable for generating a magnetic field; a cryostat for containing and preserving said SC electromagnet at a low temperature; at least two magnetic conveyors connected at opposite ends of the cryostat for conveying the magnetic field generated by the SC electromagnet to the wall of the pipeline and facilitating the closing of a magnetic circuit; at least one sensor system for revealing the intensity of the magnetic field. The inspection apparatus advantageously allows the localization of possible structural imperfections or anomalies of the walls of a pipeline, using a more efficient magnet with respect to those normally used in the "pigs" known in the state of the art.

MRI Apparatus and Quenching Prevention Device
Hitachi, Ltd.
Jan. 3, 2017
U.S. Patent No. 9536649
In order to prevent quenching caused accidentally in a SC magnet, an MRI apparatus vibrates the SC magnet in order to prevent quenching of the SC magnet in a time period for which a predetermined imaging sequence is not executed. As a specific method, a gradient magnetic field may be generated by a gradient magnetic field coil for an imaging sequence of the MRI apparatus, or a gradient magnetic field may be generated using a gradient magnetic field coil for vibration provided apart from the gradient magnetic field coil for an imaging sequence. In addition, in a period for which the predetermined imaging sequence is not executed, a phantom may be imaged to prevent the quenching of the SC magnet.

Filter having a Dielectric Insert with SC Film
Institute of Physics, Chinese Academy of Sciences; Beijing Huaront; Tianchuang Superconduct Tech Dev Co; University of Science and Technology Beijing; Usikov Inst Radiophysics & Electronics; NASU
Jan. 3, 2017
U.S. Patent No. 9537195
A band-pass filter having a body, a rectangular waveguide, and a dielectric insert, the dielectric insert has a dielectric plate and a HTS film in line with rectangular windows of the same height. The waveguide has a $\times$ b cross-section, a being length of the long side walls and b the length of the short side walls. Each long side wall has a fixing groove at the central portion and a rectangular recess in the fixing groove. The dielectric plate has two ends in the fixing grooves and is symmetric with a perpendicular bisecting plane of the long side wall. The rectangular recess is symmetric to the perpendicular bisecting plane and has the same length as that of the waveguide, with its width w satisfying $t<w<a/2$, and depth d satisfying $d<\lambda/4$, t being total thickness of the dielectric plate and the HTS film, and λ the wavelength of the central frequency of the pass-band of the band-pass filter.

Rotor for an Electric Machine
SIEMENS AKTIENGESELLSCHAFT
Jan. 3, 2017
U.S. Patent No. 9537374
A rotor form electric machine includes a rotor body that rotates about an axis of rotation, the rotor body having a SC rotor winding and cooling arrangement provided for cooling the rotor winding having at least one pair of cooling tube loops disposed substantially radially opposite each other on the rotor body, wherein a cryogenic coolant is transported in

the axial direction in the coolant tube loops from a first axial rotor end to a second, opposite axial rotor end and back when the rotor rotates about the axis of rotation. One or more connecting tubes are provided in the cooling arrangement and connect one cooling tube loop to the other cooling tube loop.

Wind Turbine having a HTS Generator

ENVISION ENERGY (DENMARK) APS

January 10, 2017

U.S. Patent No. 9541064

A wind turbine has a wind turbine tower with a nacelle provided on the top to which a rotor hub with one or more wind turbine blades is rotatably mounted by a rotor shaft. A generator is arranged in the nacelle, wherein the SC rotor coils induce a current in the stator coils when the rotor is rotated, and wherein the stator coils are arranged in at least four phases. One or more converter modules convert the power output from the generator so that it matches the power of a power grid. The generator side of the converter modules comprises a number of rectifying circuits equal to the phases in the generator, while the power grid side comprises a number of inverting circuits equal to the phases of the power grid. This allows the transient of the electromagnetic brake torque relative to the nominal electromagnetic torque of the generator to be reduced. The ripples of the electromagnetic torque are also reduced since the switching frequency of the converter is increased. This in turn reduces the mechanical stresses occurring in the drive train in the event of a failure or error occurring in one of the converter modules. The present invention also relates to a method of operation of such a wind turbine where the defective converter module is selectively switched off and the wind turbine is put into operation again at a lower operation level.

SC Magnets with Thermal Radiation Shields

Siemens PLC

Jan. 10, 2017

U.S. Patent No. 9543066

A cylindrical SC magnet has a number of axially-aligned annular coils of SC wire, arranged for cooling by thermal conduction through a cooled surface in mechanical contact with the coils. The coils are provided with a cryogenic radiation shield located between respective radially inner surfaces of the coils and respective axes of the coils. The cryogenic radiation shield is formed of a metal layer in thermal contact with the cooled surface.

High-pinning Microstructures in Post-production

YBCO Conductors

UChicago Argonne, LLC

Jan. 10, 2017

U.S. Patent No. 9543496

A method comprising irradiating a polycrystalline rare earth metal-alkaline earth metal-transition metal-oxide SC layer with protons having an energy of 1 to 6 MeV. The irradiating process produces an irradiated layer that comprises randomly dispersed defects with an average diameter in the range of 1 to 10 nm.

SC Coil Protection Method and Magnet

National Institute for Materials Science; Japan Superconductor Technology, Inc.

jan. 10, 2017

U.S. Patent No. 9543754

An object of the present invention is to provide a method for protecting a SC coil, which method prevents damage to the SC coil caused by a quench or the like, in a new way, without using a voltage (a change in voltage) generated in the SC coil. Provided is the method for protecting a SC coil made by winding tape-like SC wire having a SC layer. Power from a power supply is shut off based on the magnitude of a screening field, which is a difference between a measured magnetic field B in a direction of a thickness of the SC wire at a predetermined position, and a magnetic field Bcal in the direction of the thickness of the SC wire calculated disregarding an effect of screening current.

Phase-mode Based SC Logic

Microsoft Technology Licensing, LLC

Jan. 10, 2017

U.S. Patent No. 9543959

A device including Josephson junctions, and a terminal for receiving a sinusoidal clock signal for providing power to the Josephson junctions, is provided. The device further includes a terminal for receiving an input signal, a clock terminal for receiving a return-to-zero clock signal, and at least one latch. The device also includes at least one logic gate including at least a subset of the Josephson junctions, for processing the input signal and the return-to-zero clock signal to generate a first signal for the at least one latch. Additionally, the device includes at least one phase-mode logic inverter for processing the return-to-zero clock signal to generate a second signal for the at least one latch. The device also includes an output terminal for providing an output of the at least one latch by processing the first signal and the second signal.

Vortex Flux Generator

Silicon Turbine Systems, Inc.

Jan. 17, 2017

U.S. Patent No. 9548681

A method and apparatus for generating electricity by electromagnetic induction, using a magnetic field modulated by the formation, dissipation, and movement of vortices produced by a vortex material such as a type II SC. Magnetic field modulation occurs at the microscopic level, facilitating the production of high frequency electric power. Generator inductors are manufactured using microelectronic fabrication, in at least one dimension corresponding to the spacing of vortices. The vortex material fabrication method establishes the alignment of vortices and generator coils, permitting the electromagnetic induction of energy from many vortices into many coils simultaneously as a cumulative output of electricity. A thermoelectric cycle is used to convert heat energy into electricity.

Digital RF Transceiver System

Hypres, Inc.

Jan. 17, 2017

U.S. Patent No. 9548878

A transceiver architecture for wireless base stations wherein a broadband radio frequency signal is carried between at least one tower-mounted unit and a ground-based unit via optical fibers, or other non-distortive media, in either digital or analog format. Each tower-mounted unit has an antenna, analog amplifier and an electro-optical converter. The ground unit has ultrafast data converters and digital frequency translators, as well as signal linearizers, to compensate for nonlinear distortion in the amplifiers and optical links in both directions. In one embodiment, at least one of the digital data converters, frequency translators, and linearizers includes SC elements mounted on a cryocooler.

SC Coil and SC Device

FUJIKURA LTD.

Jan. 24, 2017

U.S. Patent No. 9552913

A SC coil includes: first and second pancake coils that are formed by winding a SC wire, are stacked in a thickness direction, and are adjacent to each other; and a cooling substrate that is provided in contact with an end surface of the first pancake coil and is separable into a plurality of cooling plates.

Method for Manufacturing SC Wire

FURUKAWA ELECTRIC CO., LTD.; CHUBU ELECTRIC POWER COMPANY, INCORPORATED

Jan. 31, 2017

U.S. Patent No. 9558873

A method for manufacturing a SC wire material in which the SC current is not saturated even when a SC layer is made into a thick film, and a SC wire material. In the method a SC layer is formed on a metal substrate interposed by an intermediate layer, the method including heating the metal substrate up to the film-formation temperature of a SC film for forming the SC layer, forming a SC film having a film thickness of at least 10 nm and no more than 200 nm on the intermediate layer, and reducing the metal substrate temperature to a level below the film-formation temperature of the SC film, and the SC film-formation, including the heating, the film-formation, and the cooling, are performed a plurality of times.