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

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- EVIDENCE FOR NEW FORM OF ELECTRON PAIRING
- KOC U PROPOSES QUANTUM HEAT ENGINE
- SC ENHANCEMENT SEEN VIA DECOMPRESSION
- YALE DEVELOPS ACOUSTIC SC QUANTUM CHIP
- AMES LAB LEADS STUDY OF CAKFE4AS4
- UCL DEVELOPS LOWER-LOSS SC NANOWIRE CIRCUITS
- YALE, BNL IDENTIFY ELECTRON FLOW IN LSCO
- TEAM FINDS UNUSUAL STATE IN CHROMIUM ARSENIDE
- AMSC PURCHASES INFINIA TECHNOLOGY CORP.
- *SUPERCONDUCTIVITY ROUNDUP*
- *SUPERCONDUCTIVITY STOCK INDEX*
- *U.S. SUPERCONDUCTIVITY PATENTS*

# AMSC Awarded U.S. Navy Contract for Installation of Superconducting SPS

AMSC has been awarded a contract from the U.S. Navy for a HTS-based Ship Protection System (SPS) to be deployed on the Fort Lauderdale (LPD 28). The scope of the contract is expected to include integration and commissioning of the system.

LPD 28 is a next generation amphibious landing dock ship (LX(R)) based on a modified San Antonio-class platform. The LPD 28 is considered a bridge between the San Antonio-class design and future LX(R) vessels. The SPS will provide the LPD 28 with mine protection while reducing the weight of the degaussing system by 90% and lowering energy consumption by more than half that of legacy degaussing systems.

## SPS Viewed as First Step for Broader Insertion of HTS Applications

AMSC and the Navy have long collaborated on the company's HTS-based SPS. The system's core components are designed to be transferable to other applications being targeted for naval ships. AMSC President and CEO Daniel McGahn has stated in the past that SPS is intended to provide the Navy with an opportunity to become comfortable with HTS technology in advance of large-scale adaptation of other HTS components for applications such as power and propulsion.

Last spring, AMSC announced that it had been awarded an $8.4 million contract for engineering and technical services (see *Superconductor Week*, Vol 31, No 5). The sole source contract was entered into to support the Navy's insertion of SPS into the fleet and encompasses interface hardware for testing and training systems as well as test support related to HTS technology.

## LPD 28 to Project Military Power Ashore

The 13 ships of the USS San Antonio-class are an important element of the U.S. Navy's ability to project power ashore. Collectively, they functionally replace more than four classes of 41 amphibious ships. The San Antonio-class ships are 684 feet long and 105 feet wide and displace approximately 25,000 tons. Their principal mission is to deploy the combat and support elements of Marine expeditionary units and brigades.

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The ships can carry up to 800 troops and will have the capability of transporting and debarking landing craft air cushions or conventional landing crafts, augmented by helicopters or vertical take-off and landing aircraft such as the MV-22. They will support amphibious assault, special operations, or expeditionary warfare missions during the first half of the 21st century.

### AMSC Purchases Infinia Technology Corp.

AMSC also announced that it has acquired Infinia Technology Corporation (ITC), a cryocooling company located in Richland, WA that was founded in 2009. AMSC paid the selling stockholders an aggregate purchase price of $3.75 million including $100,000 in cash and 884,890 shares of AMSC common stock.

AMSC has suggested that the acquisition of ITC allows it to control the production of a key SPS element. AMSC expects the acquisition to allow for the expansion of SPS margins while increasing the overall AMSC content per SPS and ensuring enhanced quality of content in SPS products.

"AMSC currently has PowerModule technology in its electrical control systems and D-VAR products," said McGahn. "ITC adds high performance cryocooling to our system-level solutions and represents an opportunity for a ColdModule technology for AMSC's SPS product. This addition helps expand our portfolio of proprietary technology and adds system-level value beyond the production of our wire."

ITC holds several U.S. government contracts including ones involving cryocoolers for the U.S. Navy. The company claims that its cryocoolers outperform commercially available alternatives from both an efficiency and noise perspective and will enable 50% more cooling power for AMSC's SPS. ❍

## STI Fixing Cap Layer Problem with Conductus Wire

Superconductor Technologies Inc. (STI) announced in its Q2 FY2017 earnings report conference call that the cap layer on its superconducting Conductus wire shipped to potential customers was thinner than specifications. Feedback from customers confirmed these findings.

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"As the $I_c$ in our wire increases, the cap layer must be sized appropriately to protect the wire from damage when a higher current is applied," commented Jeff Quiram, STI's President and CEO, during the earning conference call. "To ensure correct cap layer thickness is being applied to Conductus wire going forward, we have implemented additional quality control enhancements in our manufacturing process."

Quiram acknowledged during the conference call that the quality control issue would set back efforts to qualify Conductus wire for various customer projects: ì Unfortunately, every time we have one of these problems it just sets us back and you kind of restart the clock on the testing. We believe we're going to get some in-specification cap layer samples in the near future, and then we'll ship them off to the customers and get through their testing process. But everything has to go right, and we can't really have any more hiccups on some of these things."

### DOE Project Underway

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 are in collaboration with our partners, and will build and validate a 500-plus horsepower motor coil in a project in test fixture. The DOE objective is to also reduce the cost of wire to $50/kA-m for the wire."

### Cash on Hand will Fund Operations Through Q1 FY2018

For Q2 FY2017, STI reported net revenues of $8,000, a 37.3% decline from Q2 FY2016 revenues of $11,000. The revenues were primarily realized from legacy wireless products. The quarterly net loss was $2.5 million compared to $2.6 million over the comparable quarter last year.

For the first half of FY2017, STI reported revenues of $9,000, a 91% decline from $100,000 in revenues during the first half of FY2016. Net loss declined slightly to $85.2 million from $85.7 million. The company's share price fell by 12.5%, from $1.28 to $1.12, on the day of the earnings announcement.

STI held $6.4 million in cash on its balance sheet at the end of Q2 FY2017 compared to $8.4 million at the end of the previous quarter. In the earnings conference call, CFO Bill Buchanan stated that existing cash resources would be sufficient to fund planned operations through Q1 of FY2018. ❍

## Japanese Team Fabricates 3 µm-thick NbN Film for Compact SMES

Researchers with Nagoya University, the Toyota Technological Institute, Kanto-Gakuin University, D-Process Inc., Aisin Seiki Co. Ltd., and Toyota Central R&D Labs have reported the fabrication of a traversable 3 micrometer-thick NbN film for a superconducting coil formed using MEMS technology (10.1088/1742-6596/897/1/012019). The coil is intended for use in a compact SMES device with a high energy storage volume density. The study is based on results from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

### Project First Funded in FY2015

"The NEDO Advanced Research Program for Energy and Environmental Technologies that this study is a part of has admitted applications from Japanese applicants since FY2014 and will continue to do so through FY2018," said Nagoya University's Tomoyoshi Motohiro, who co-authored the study. "10 to 20 applications are adopted every year. The goal of the program is to admit applications on game-changing technologies in energy saving, the development of new energy resources, and the reduction of $CO_2$ emissions.

"The goal of our project was to create a new option for electric energy storage or a buffer. Our project was adopted for FY2015. Almost all the

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projects funded through the NEDO program are one-year projects, with some exceptional two-year projects also receiving grants.

"Our project started on Oct. 26, 2015 and ended Oct. 31, 2016. However, we received an extension beginning Jan. 4, 2017 through Jan. 31, 2018.

"The total budget of NEDO's Advanced Research Program for Energy and Environmental Technologies is ¥2.6 billion ($23.2 million) for FY2017. For FY2015, our project received ¥100 million ($890,000). The extension our project received was funded ¥20 million ($180,000)."

## Design Represents Novel Approach to SMES Construction

The coil fabricated for the study was lined with a 42 m-long Cu-plated layer in a spiral, three-storied trench engraved in and extended over a whole silicon wafer with a diameter of 76.2 mm. The design is based on a previous proposal by the development team.

The design represents a novel approach to the construction of a compact SMES unit composed of a stack of silicon wafers fabricated using a MEMS process. The study's authors argue that the method may bring the SMES device closer to competing with more traditional mass-produced capacitors as a storage technology for renewable energy.

"SMES has been developed in the field of heavy electric machinery," said Motohiro. "Thin film coils have also been developed in microelectronic circuits. We just combined the two different fields.

"We decided to embed the superconducting coil in a spiral trench to protect it from the possibly strong electromagnetic forces that the thin film coil is exposed to, particularly in the case of a superconductive coil. The spiral trench can be fabricated via a MEMS process.

"An optimistic calculation predicts that the energy storage volume density of our system can reach 9.7 Wh/l using NbN. However, if we consider the need for a cryogenic refrigerator, magnetic shields, and so forth, this figure drops to 1.8Wh/l. A typical value for a conventional gigantic SMES is 0.88 Wh/l for a capacity of 5.6 kWh and where NbTi superconducting cables are employed.

"The size of such a conventional SMES is about 1.85 m × 1.85 m × 1.85 m. To attain the same capacity of 5.6 kWh, our system would be about 1.46 m × 1.46 m × 1.46 m. In the calculation we assumed a $J_c$ value for NbN of 1100 A/mm$^2$.

"Another route to making the SMES smaller is to use a different superconductor with a higher $J_c$ than NbN. YBCO, for example, may be able to reach $J_c$ values 18 times greater than NbN. The SMES can in theory be made smaller up to the limit of the highest electromagnetic force that can be borne by the silicon wafers."

## System almost Competitive with Traditional Capacitors

Motohiro added that the system was close to being competitive with traditional capacitors: "If we consider a 'traditional capacitor' as one with a capacity of 600 F and that operates under 3 V, the energy it stores would be 2.7 kJ or 0.75 [Wh]. The optimistic value of 1.8 Wh/l for our NbN system needs 0.42 l to attain a capacity of 0.75 [Wh].

"We therefore believe our system will be able to compete with 'traditional capacitors' in the near future. However, we think we must overcome many difficulties to compete with secondary batteries.

"We used multi-step MEMS processes [to fabricate the silicon wafers], and these are essentially mature processes developed by the semiconductor industry. If mass production is necessary, they can be fully automated. Our SMES is composed of many silicon wafers formed via a semiconductor microfabrication process.

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"A similar product is a photovoltaic panel. The price of PV panel was $70 per Watt in 1976 and is exponentially decreasing with the increase in cumulative manufactured capacity.

"It is projected to reach $0.40 per Watt in 2035. Therefore we can expect a cost reduction to some competitive level via mass production."

## Coils Achieve Peak $I_c$ of 220 mA at 4 K

The coils reached a peak $I_c$ of 220 mA at 4 K, five times as larger than the $I_c$ recorded in the device used as an experimental proof-of-concept in the team's previous report.

In the previous study, the team achieved an $I_c$ of 43 mA at 3.7 K in a device with 9.9 µJ of magnetic storage. The NbN film used in both the previous and current studies superconducts at a $T_c$ of 15.5 K.

The device in the current study has a magnetic storage capacity almost 10 times higher than that in the previous study. The energy storage volume density of 9.7 Wh/l is fairly large in comparison with a typical value for conventional gigantic SMES of 0.88 Wh/l

"In the present paper we attained a storage capacity of 93 µJ on a silicon wafer of 76.2 mm in diameter. This corresponds to $1.9 \times 10^5$ [Wh/l]. We were able to increase the magnetic storage capacity from 9.9 µJ on a 101.5 mm diameter Si wafer to 93 µJ on a 76.2 mm diameter Si wafer due to three factors.

ìFirst, we increased the cross-sectional area of the trench from 35 $\mu m^2$ to 590 $\mu m^2$. Second, we increased the thickness of the NbN thin film from 0.5 µm to 3 µm. And third, we removed the defects in the spiral coil to attain a complete full-length coil."

## Si Wafer with 101.5 mm Diameter Preferable to 76.5 mm

Motohiro explained that the system performance improved with larger wafer diameters: "We used a silicon wafer with a 101.5 mm diameter in our previous study. Although we think we attained a proof-of-concept, we were not successful in complete fabrication of the defect-free coil throughout the wafer.

"In the present study, we fabricated a wafer with a 76.5 mm diameter. Since we constructed our concept and estimated the performance for a silicon wafer with a 101.5 mm diameter, we would like to realize our concept using a wafer made of silicon with those dimensions.

"We are now working on a wafer with a 101.5 mm diameter. The 101.5-mm wafer will be better than the 76.5 mm variant because it results in longer coils with higher inductance. 101.5 mm is not necessarily the best diameter, but it is the largest one we can fabricate using our MEMS process apparatuses."

## Team Plans Series-connected Two-wafer Coil using SC Joints

The completion of a one-wafer superconducting NbN coil is an important step for the next proof-of-concept, the fabrication of a series-connected two wafer coil via a superconductive joint. The team plans to eventually connect a series of 600 wafer coils and replace the LTS NbN with an HTS materials such as YBCO cooled via liquid hydrogen or liquid nitrogen.

"There are many unknown factors in the microfabrication process of YBCO, such as methods to attain preferential crystal orientation of the thin film, methods of flux stabilization, methods to prevent corrosion of YBCO during the copper electroplating process, selective polishing in CMP, etc.," commented Motohiro. "We therefore began with NbN because it was much easier to attain the proof-of-concept.

"The $J_c$ of YBCO is expected to be about 18 times larger than that of NbN. This means that

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YBCOís energy storage density could be 18 × 18 times larger than that of NbN. In reality, YBCOís high $J_c$ results in high electromagnetic forces which might destroy the silicon wafer. We therefore need to find a compromise between the $J_c$ and electromagnetic force on the base of engineering in accordance with Virial theorem.

"We are now dealing with various problems to substitute the materials necessary to transition from NbN to YBCO. It is difficult to say when this process will be complete.

"As for connecting multiple wafers, we are also going step-by-step beginning with building a two-wafer connection. It is difficult to say when this process will be complete, and it is additionally dependent on the possibility of future funding.

"Regarding the major challenges, in order to create a connected system of 600 wafers one must attain a good connection between superconducting thin films on neighboring wafers as well as well-established copper films. In our 4 K cryostat of 5 W, the maximum thickness of the sample is 5 cm, that is, a system of 100 wafers. To evaluate the performance of a 600 wafer system, we need another cryostat system as well as a bonding system." ❍

## BNL-lead Team Finds Evidence for New Form of Electron Pairing

Researchers with Brookhaven National Lab (BNL), the University of Copenhagen, the University of Leipzig, the Ames Lab, Iowa State University, Binghamton University, the University of Florida, Gainesville, the University of St Andrews, and University College Cork have published a study of the electronic structure of FeSe that has found evidence for a new type of electron pairing that may broaden the search for new high-$T_c$ superconductors (10.1126/science.aal1575). The findings provide the basis for a unifying description of how radically different parent materials, such as insulating copper-based compounds and metallic iron-based compounds, can display superconductivity. The research was conducted under the auspices of the Center for Emergent Superconductivity, a DOE Energy Frontier Research Center located at BNL (see *Superconductor Week*, Vol 23, No 10).

Scientists have understood that the mechanism of superconductivity in cuprates depends on the ability of electrons on adjacent copper atoms to pair up. Each copper atom has a single, unpaired electron in its outermost orbital.

While the outermost electrons on adjacent copper atoms interact with one another strongly, they ordinarily stay locked in place. With no electrons moving, the material acts as a strongly correlated electrical insulator.

Removing some of the electrons that reside on copper atoms results in electron vacancies known as holes. This means that when the material is cooled to a certain temperature, oppositely-aligned electrons form pairs that enable superconductivity.

### New Study First Direct Proof of Orbital-selective Electron Pairing

Iron atoms, which have a nucleus with smaller positive charge than copper, exert less pull on the circulating electrons. This means that instead of filling up electron orbitals, electrons in several outer energy orbitals remain unpaired, yet aligned with one another and electronically active.

The alignment of unpaired electrons in multiple orbitals gives simple iron its strong magnetic and metal properties. It remains unclear, however, how they could become superconductors at high temperatures without the strong interactions that create a correlated insulating state in the copper-based materials.

In order to bridge the gap between the two major HTS families, theoretical physicists began to consider the possibility that the unpaired electrons

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in iron's different orbitals could take on different roles. They considered the possibility that unpaired electrons in one orbital could pair up with electrons in the same orbital on an adjacent atom to carry the supercurrent, while electrons in the other orbitals provide the insulating, magnetic, and metallic properties. The recent study represents the first direct proof that such orbital-selective electron pairing takes place. ❍

## Koc U Proposes Quantum Heat Engine with SC Resonators

Researchers with Koc University in Istanbul, the Technical University of Denmark, and the University of Waterloo have proposed a quantum heat engine (QHE) based on coupled superconducting resonators. QHEs use a quantum working substance to generate power from the heat flow between hot and cold reservoirs. The research was supported by the Villum Foundation and separate research agreements between the Lockheed Martin Corporation and Koc University and the University of Waterloo.

"QHEs can be seen as analogous to quantum computers,î said Ozgur Mustercaplioglu, Researcher at Koc U who co-authored the study. ì QHEs have similar operational abilities as quantum computers but for energy processes instead of for computations. Accordingly, they are expected to outperform their classical counterparts, especially in the efficient manipulation of energy processes such as faster energy transport.

"There are experimental reports suggesting that nature already utilizes quantum advantages in biological systems, for example in light harvesting complexes. At their current level of development, QHEs would be ideal for the rapid harvesting of a faint thermal energy resource to low coherent power."

"We are not interested in any specific device platform at the moment but to assess the potential benefits of 'quantumness' in a general thermal engine. The proposed QHE system can be compared to a single atom piston engine, which was recently realized in an ion trap in the classical regime and has attracted much attention.

"It is an all-electrical on-chip analog of a piston-type engine that operates via periodic coupling to an electrical thermal noise source. Using typical superconductor transmission line resonator parameters, a power output five orders of magnitude greater than the single-atom engine with similar efficiency values can be realized."

### SC Transmission Lines Linked via Optomechanical Coupling

The researchers propose a QHE composed of two superconducting transmission line resonators interacting with each other via an optomechanical-like coupling. In the proposed design, one resonator is periodically excited by a thermal pump. The incoherently driven resonator induces coherent oscillations in the other one due to the coupling.

Using such a design, a limit cycle, which indicates finite power output, emerges in the thermodynamical phase space. The system implements an all-electrical analogue of a photonic piston. Instead of mechanical motion, the power output is obtained as a coherent electrical charging.

"The rate of coherence building in one resonator is correlated with its cause, the electrical pressure of the other resonator," said Mustercaplioglu. "This quantum correlation contributes to and enhances the power output of the engine beyond that of a classical heat engine.

"Relative to typical mechanical piston engines, the optomechanical coupling and quantum effects can be stronger in electrical versions. Further, they offer direct interfacing advantages for all-electrical applications without the requirement of a mechanical motion-to-current conversion."

### SC Transmission Line Resonators Enable Quantum Harmonic Oscillations

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Mustercaplioglu said that it was important that the transmission line resonators be superconducting: "The superconducting character of the transmission line resonators allows them to be modelled as quantum harmonic oscillators. Such a quantum character is essential for establishing the required quantum correlations between the resonators for power enhancement.

"These quantum correlations can be sufficiently strong in superconducting resonators to lead to significant quantum enhancement of the power output. In our implementation of the design we use standard microwave stripline superconducting resonators, which are typically made from aluminum or niobium.

"The energy gaps of the superconducting resonators relative to the operational temperatures of the engine are wide enough to make their discrete nature significant for the description of the QHE. In addition, the optomechanical coupling constant is comparable to the frequency of the coherently charged resonator, which is a relatively strong coupling regime of optomechanics.

"The thermal noise sources are not engineered, but typical white noise drives. The output power is oscillatory and not rectified.

ì The engine operates with two heat strokes but effectively behaves as an Otto engine. Such details make a difference on the beneficial use of the specific quantum correlation that can enhance the power output, while in other designs quantum correlations can have no effect or even cause degradation of the engine performance."

### QHE has a Maximum Power Output of ~$3 \times 10^{16}$ W

As part of their study, the researchers conducted a series of calculations that suggests that the quantum enhancement of the power output of the engine is maximized at low temperatures. Mustercaplioglu elaborated on his team's findings: "The engine operates in a cold environment provided by a dilution fridge of ~20 mK. The thermal noise drive associated with a temperature of ~5 K yields the maximum power output.

"The maximum power output of this design is ~$3 \times 10^{16}$ W. The working substance is the photon gas in the thermally driven resonator with a frequency of ~10 GHz. The mass of the resonator is ~0.3 grams while the host chip has dimensions on the scale of a few centimeters.

"A major challenge to building a prototype of the proposed engine is to reach the strong optomechanical coupling needed between the resonators. In addition, additional decoherence effects when the external loads are attached can degrade the quantum coherence and correlations in the QHE.

"We are planning to build a prototype engine or at least some modules of the design to test the feasibility of this QHE. As proposed in the study, a fruitful next step in the development of this QHE would be using a quantum-squeezed thermal noise source to increase the quantum correlations for further enhancement of the power output." ❍

## HPSTAR Team Sees SC Enhancement with Decompression

Researchers from Shanghai's Center for High Pressure Science and Technology Advanced Research (HPSTAR), the University of California, Jilin University, Nanjing University, and the Carnegie Institution of Washington have observed that decompressing the layered 2D chalcogenide $In_2Se_3$ results in a higher $T_c$ (10.1002/adma.201701983). This unusual superconductivity enhancement implies that it would be possible to maintain pressure-induced superconductivity at lower or even ambient pressures with better superconducting

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performance. The work received financial support from the National Natural Science Foundation of China (NSFC).

A long-term challenge to enhancing pressure-induced superconductivity has involved its preservation as the material decompresses or quenches. Successfully maintaining superconductivity could open up a variety of practical applications for materials that would otherwise be difficult to utilize.

## 2D Chalcogenide Exhibits Unusual Electronic States Variation

For their study the researchers chose layered $In_2Se_3$ because its 2D electronic structure can be modulated by external pressure. In addition, the pressure-modulated modifications of these substances exhibit irreversible character during decompression, which could be beneficial for achieving pressure-quenchable superconductivity. $In_2Se_3$ is also extremely sensitive to external conditions, shows large electronic anisotropy between in-plane and cross-plane conductivity, and has a large resistance variation between different electronic states with varying external conditions.

Furthermore, the pressure-driven 2D-3D structural crossover in $In_2Se_3$ is different from the transition in other layered chalcogenide materials, indicating the unusual variation of its electronic states. The researchers carried out electrical transport measurements on single crystalline $In_2Se_3$ during compression and decompression cycles, complemented by x-ray diffraction (XRD) experiments to monitor the structural evolution.

"The different transition path of $In_2Se_3$ from other layered chalcogenides may result from their different transition mechanism," commented HPSTAR Shanghai Lab Director Bin Chen. "The structural transition of $In_2Se_3$ may arise from the changes of atomic radii of In and Se in compression."

## $T_c$ Increases more than Twofold at Lower Decompression Pressures

The team determined that the onset of superconductivity in $In_2Se_3$ occurred at 41.3 GPa with a $T_c$ of 3.7 K, and peaked at 47.1 GPa. Reducing pressure, they observed that the material remained superconducting in down to 10.7 GPa. More surprisingly, the compound realized a $T_c$ of 8.2 K at lower decompression pressures, a more than two-fold increase in the same crystal structure when in compression.

In most cases, pressure compression has a reversible modulation on superconductors. For example, the evolution of $T_c$ in decompression follows the reverse trend in compression, and pressure-induced superconductivity often fades away or disappears with releasing pressure.

## Phonon Softening may affect $T_c$

To investigate the structural cause of this phenomenon, the team carried out in-situ high-pressure x-ray diffraction (XRD) measurements for structural characterization. They found that, with compression up to 35.6 GPa, a new structure takes form, and the structural transition completes above 46.3 GPa. The high-pressure phase remains stable up to the highest pressure we looked at, 52.8 GPa.

The researchers suggested that the evolution of $T_c$ may be driven by the pressure-induced R-3m to I-43d structural transition, with significant softening of phonons and gentle variation of carrier concentration combined in the pressure quench. The quenchable high-pressure phase may be due to the 2D-3D structural crossover in $In_2Se_3$ under compression.

Pressure compression usually results in phonon stiffening, which is responsible for the drop of $T_c$ above 47.1 GPa. In contrast, phonon softening occurs due to decompression, and the carrier concentration remains almost unchanged until below 10.7 GPa.

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### Team to Explore Decompression in Other Compounds

Phonon softening results in the enhancement of $T_c$ down to 10.7 GPa. Below 10.7 GPa, the carrier concentration drops sharply with decreasing pressure, which gives rise to weaker electron-phonon coupling and consequently the loss of superconductivity.

"Some other compounds, for example 2D materials, may also show a similar enhancement of superconductivity via decompression," Chen said. "Their pressure-induced electronic and structural properties usually show an irreversible character in decompression and can be preserved at low pressures.

"The highest $T_c$ achieved to date was through high-pressure compression, such as 164 K in a copper oxide system and 203 K in a compressed sulfur hydride system. We will study these layered high-$T_c$ superconductors, including layered cuprate- and iron-based superconductors, and attempt to preserve their high $T_c$ at low and even ambient pressures." ❍

## Yale Develops Acoustic Superconducting Quantum Chip

Researchers with Yale University have created a simple-to-produce device that uses sound waves to store quantum information and convert it from one form to another inside a single, integrated superconducting chip (10.1126/science.aao1511). The device allows a superconducting qubit to exchange energy and quantum information with a high frequency bulk acoustic wave resonator (HBAR).

The ability to manipulate and store fragile quantum data in a robust and easy-to-manufacture way is a crucial step in the development of quantum computing technology. The work received support from the U.S. Army Research Office.

### First Acoustic Wave Resonator Demonstrated in 2010

"An acoustic resonator is a useful tool when combined with a superconducting circuit because it can help store and transduce quantum information," said Yiwen Chu, Yale University Researcher who co-authored the study. "We realized that there was a simple and robust way of making such a device.

"A device of this type was first demonstrated in 2010 (10.1038/nature08967). Our device, however, is much easier to make and performs better. In testing, our device performed well and matched our theoretical expectations, demonstrating clear improvements from earlier systems.

"One application [that this technology is particularly suited for] is building quantum networks, where quantum information has to potentially be stored for long periods of time and converted between different physical forms. Our mechanical resonator may be able to do both.

"One drawback [of such a device] is that sound waves propagate inside the complex environment of a material, and any imperfections in the material could limit its coherence time. We are currently trying to study and understand to what extent this is a limitation."

### Qubit made from Superconducting Aluminum

The new device features a qubit made from superconducting aluminum and a mechanical resonator made with a sapphire wafer. The wafer has two polished surfaces acting as mirrors for sound waves.

A single quantum particle of sound, a phonon, has a long decoherence time when bounced between the two mirrors. When coupled to a superconducting qubit on the surface of the sapphire using a disk of aluminum nitride, the acoustic energy can be converted into

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electromagnetic energy and vice versa.

"The lifetimes of the phonons were longer than the superconducting qubit they were coupled to," said Chu. "However, they were shorter than state-of-the-art superconducting resonators."

### Quantum State Transferred between Qubit, Resonator

The device enabled the researchers to transfer quantum states back and forth between the qubit and the mechanical resonator. The new device is also easier to manufacture than other systems that merge superconducting circuits with mechanical motion.

"The geometry and materials used [in our device] are very simple," said Chu. ìOur mechanical resonator is just a wafer of sapphire, and there are no suspended structures like in many other micromechanical devices.

"In principle [this technology is easily scalable] due to its robust and simple design. The physical device is also very compact and supports many individual phonon modes in a small volume.

"[In terms of next steps], we want to further improve the performance of the device by increasing its coherence times and coupling strengths. We then want to use it to store and transduce quantum states." ❍

## Ames Lab Leads Study of $CaKFe_4As_4$

Researchers with Ames Lab, Iowa State University (ISU), and Goethe University Frankfurt am Main have published a study of the superconducting properties of $CaKFe_4As_4$ using 75As NMR (910.1103/PhysRevB.96.104512). Funding for the research was provided by the U.S. DOE, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Contract No. DE-AC02-07CH11358, and by the Deutsche Forschungsgemeinschaft (DFG).

The study is a part of a research project on Complex States, Emergent Phenomena, and Superconductivity in Intermetallic and Metal-like Compounds at the Ames Lab. The goal of the project is to develop, discover, understand, and ultimately control and predictably modify new and extreme examples of complex states, emergent phenomena, and superconductivity.

### $CaKFe_4As_4$ Potential Candidate for Transmission Lines, Magnets

"$CaKFe_4As_4$ is the most recent addition to the family of iron-based superconductors," said ISU's Yuji Furukawa, who co-authored the research. "It has a different crystal structure (P4/mmm) from the well-known 122 system (I4/mmm) and exhibits superconductivity at a relatively high $T_c$ of 35 K.

"The material's crystal symmetry may be related to new properties which are not present in other materials. Performing a detailed study to compare $CaKFe_4As_4$ with other well-studied iron-based superconductors will provide clues about the origin of HTS in iron-based superconductors.

ì$CaKFe_4As_4$ also has a very high, almost isotropic, $H_{c2}$ of 92 T. This makes it a potential candidate for applications in power transmitting lines and superconducting magnets.

"Because magnetic fluctuations are considered one of the drivers of superconductivity in iron pnictides, it is important to characterize the dynamical properties of the iron moments. We therefore employed the 75As NMR. Furthermore, the nuclear spin-lattice relaxation rate and Knight shift measurements in the superconducting state also provided important information for understanding the gap structure."

### First Observation of Hedgehog-spin Correlations

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The analysis revealed that the K and Ca layers in $CaKFe_4As_4$ are well ordered without site inversions. The researchers also found that a new type of antiferromagnetic spin fluctuation is created by the so-called hedgehog-type spin vortex crystal correlations that exist in the paramagnetic state.

Furthermore, the researchers found evidence for the formation of spin-singlet Cooper pairs. The measurements seem to indicate that $CaKFe_4As_4$ is an s± nodeless two-gap superconductor.

"The determination of spin-singlet Cooper pairs is important to understand the pair wavefunction, which excludes a possibility of a s = 1 triplet superconducting state," said Furukawa. "The hedgehog spin correlations we found have been predicted by theoretical studies but never observed in real materials.

"This is the first observation of hedgehog spin correlations. Furthermore, our team recently discovered a long-range magnetic ordered state with the hedgehog-type spin vortex crystal structure in electron doped $CaKFe_4As_4$ (arXiv:1706.01067). This represents a new opportunity to study the relationship between the hedgehog spin vortex crystal and superconductivity." ❍

## UCL Develops Lower-loss SC Nanowire Circuits

Researchers with the London Center for Nanotechnology at University College London (UCL) have concluded a study of low-loss superconducting nanowire circuits using a neon focussed ion beam (10.1103/PhysRevApplied.8.014039). The research was funded by the UK Engineering and Physical Sciences Research Council.

"Our research, though not specifically about developing quantum computers, is relevant to the development of new quantum circuits for use in quantum technologies 2.0, which incorporate functionality based on quantum superposition and entanglement and are currently the subject of a new EU Flagship funding project," said Jon Fenton, Researcher at UCL who co-authored the research. "In these systems, obtaining low levels of loss is crucial for the 'quantumness' of the system to be maintained for long enough to be useful. Our finding of low loss both builds on previous know-how from quantum computing researchers and suggests that superconducting nanowires will be useful in future quantum circuits."

### Reducing Noise and Decoherence Key for Quantum Applications

Superconducting circuits currently have a wide range of applications in metrology and quantum devices. The active element in most functional superconducting circuits is based upon one or more Josephson junctions, which are typically formed by aluminium oxide ($AlO_x$) tunnel barriers separating superconducting leads. However, the amorphous $AlO_x$ layers can host two-level systems which contribute to noise and decoherence - effects which are particularly noticeable in the superconducting RF resonators that are ubiquitous in quantum circuits.

An alternative approach is to replace the tunnel barrier structure with a length of narrow superconductor with a width comparable to the coherence length of the superconductor. Such superconducting nanowires have shown a variety of Josephson and phase-slip effects which make them candidates for use as active elements in a range of applications in superconducting circuits.

As well as not containing an amorphous oxide tunnel barrier, superconducting nanowires have higher magnetic field resilience than tunnel-barrier Josephson junctions and are monolithic elements compatible with single-stage processing. However, previous attempts to embed superconducting nanowires into superconducting circuits have always introduced high levels of loss and dissipation.

### Design Incorporates Neon Focussed Ion

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### Beam

In the current study, the researchers present low-temperature measurements of low-loss NbN superconducting nanowire-embedded resonators in the low-power limit relevant for quantum circuits. The superconducting resonators were embedded with superconducting nanowires with widths down to 20 nm using a neon focussed ion beam.

"The design of the resonator itself is fairly standard," said Fenton. "It is the use of the neon focussed ion beam which is novel. We are essentially using the resonator as a tool to measure the losses.

"Neon focussed ion beam is a new technology with both higher resolution and potentially less sample poisoning than the conventional gallium focussed ion beam, both of which could mean lower losses. Our investigation was the first to study this."

### Internal Quality Factor of $3.9 \times 10^5$ at 300 mK Demonstrated

In the low-power limit, the research team demonstrated an internal quality factor up to $3.9 \times 10^5$ at 300 mK, implying a two-level-system-limited quality factor up to $2 \times 10^5$ at 10 mK. The values are significantly higher than in similar devices and match the state-of-the-art of conventional Josephson-junction-embedded resonators.

The researchers also showed the high sensitivity of the nanowire to stray infrared photons, which is controllable by suitable precautions to minimize stray photons in the sample environment. The results suggest that there are excellent prospects for superconducting-nanowire-based quantum circuits.

"Superconducting nanowire circuits are already used in detectors for astronomy," commented Fenton. "Quantum circuits are still in their infancy and much of the work on them has focused around Josephson junctions. Work in employing superconducting nanowires in quantum circuits is still at the development stage, but has potential future applications in calibration for high-tech industries and medical applications.

"The big improvement in terms of the low level of the losses is perhaps surprising and much better than in previous devices. It is certainly promising for future use of neon focussed ion beams. We want to do more development work on prototype quantum circuits making use of these nanowires, including developing one which could be used as a quantum standard for electrical current." ❍

## Yale, BNL Identify Symmetry-breaking Electron Flow in LSCO

Researchers with Yale University and Brookhaven National Lab (BNL) have published a study describing the symmetry-breaking flow of electrons through cuprate superconductors (10.1038/nature23290). The behavior may be linked to the mechanism behind HTS in these materials. The research was funded by DOE's Office of Science.

The researchers studied the behavior of single-crystal $La_{2-x}Sr_xCuO_4$ films through which an electrical current was being passed. They observed a spontaneous voltage develop across the sample transverse to the electric current.

The voltage is dependent on probe current, temperature, in-plane device orientation, and doping, and was observed to be robust over a broad range of temperature and doping. The amplitude of the transverse voltage oscillations peaked near $T_c$ and decreased with increasing doping.

### In-plane Rotation Symmetry Spontaneously Broken in LSCO

"The existence of a non-zero transverse voltage shows the in-plane rotational symmetry is

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spontaneously broken in LSCO," said Jie Wu, BNL Researcher who co-authored the study. "The new symmetry is a C2 symmetry that corresponds to a 180° rotation. This means the motion of carriers in LSCO is not isotropic but anisotropic.

"This is in contrary to the Fermi liquid theory. As the name indicates, liquid has no preferred directions.

ì But LSCO, as a typical member of the HTS family, is electronic nematic. The term nematicity is used as an analog to the liquid crystal to show the anisotropy of electronic system.

"This behavior can only come from the electron correlations. Our conclusion is that the normal state of HTS is electronic nematic so superconductivity emerges out of the electronic nematicity."

### Team Tests LSCO in Broad Range of Conditions

Wu added that his team tested LSCO over a wide range of temperatures and doping concentrations: "We tested the temperature from room temperature, around 295 K, to 0.3 K. We tested doping from 0.02 to 0.3, covering all the underdoped, optimal-doped, and overdoped region. We tested the voltage-current relationship for three orders of magnitude and observed the relationship to always be linear (ohmic) in the range of currents we're interested in.

"We tested all the in-plane orientations from 0° to 360° in 10° steps. In the doping-temperature phase diagram, when the doping is lower than the critical doping 0.26 and the temperature higher than $T_c$, the LSCO sample always manifested electronic nematicity.

"[These results are] a surprise to us and to the research community. People had expected the transverse voltage to be strictly zero. If the rotational symmetry is preserved and the Fermi liquid theory applies, then the transverse voltage should be zero."

### Transverse Voltage Proportional to Applied Electric Current

Wu described the transverse voltage observed in the recent study: "The transverse voltage is always proportional to the applied electric current for temperatures from room temperature to $T_c$. The transverse resistivity, defined as the ratio between the transverse voltage and the current, decreases with the temperature and shows a pronounced peak around $T_c$. This means the electronic nematicity is enhanced by the superconducting fluctuations.

"[The relationship between the transverse voltage and superconductivity in LSCO] is still an open question for future studies. All we know now is that the transverse voltage and the electronic nematicity is a result of the electron correlations.

"HTS in LSCO is also a consequence of the electron correlations. So both phenomena originate from the same interaction. However, we don't know yet whether they are collaborators or competitors. This is an important question for the strongly correlated electron physics." ❍

## Team Identifies Unusual Electronic State in Chromium Arsenide

Researchers with the Chinese University of Hong Kong (CUHK), Kobe University, and Kyoto University have observed an unusual electronic state in the new superconductor chromium arsenide (10.1038/ncomms15358). The finding could prove useful in future superconductor research and material design. The research received funding from the Research Grant Council of Hong Kong, the Chinese University of Hong Kong, the Japan Society for the Promotion of Science, and the National Natural Science Foundation of China.

"These results highlight the interplay between

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superconductivity and an unusual band crossing protected by the non-symmorphic symmetry of the space group, which gives rise to a hybrid energy-momentum dispersion relation," said CUHK's Swee Goh, a co-author of the study. "The work will inspire the search of similar physics in other superconductors with a non-symmorphic crystal structure."

## SC in Chromium Arsenide Found in 2014

The superconductivity of chromium arsenide was discovered in 2014 under pressure, and it is the first known magnetic superconductor to incorporate chromium. In contrast to the 2D layered crystal structures of iron-based superconductors and cuprates, chromium arsenide has a non-symmorphic crystal structure formed by zigzag chains of chromium. The relationship between this crystal structure and its superconductivity has drawn attention from scientists.

"Superconductivity can be induced in chromium arsenide at a pressure of about 2 kbar," said Goh. "The $T_c$ reaches a maximum of 2.2 K at 10 kbar. Due to its low $T_c$, it would be challenging to make the material into a commercial product. Nevertheless, it is an important material for fundamental superconductivity research due to its similarity with other families of superconductors with much higher $T_c$ís."

## Measurements Show Electrical Resistance Linear to Magnetic Field

The research group found that at ultralow temperatures, the electrical resistance of chromium arsenide shows a linear increase against the magnetic field. In normal metals the resistance increases as a square of the magnetic field, creating a parabolic curve, but the resistance of chromium arsenide shows a linear variation under magnetic field.

Linear magnetoresistance is usually realized under special circumstances when electrons contributing to magnetotransport are highly mobile and from the lowest Landau level. Hence, linear magnetoresistance has been observed in low carrier-density Dirac materials.

However, chromium arsenide is a metal with strong magnetic properties and very different qualities from other materials that have shown linear magnetoresistance. The special crystal structure of chromium arsenide may have created the unusual electronic state.

"To obtain these results, the data was carefully collected under multiple extreme conditions, i.e. high pressure, low temperature, and high magnetic field," said Goh. "The next steps in this line of research involve examining other superconductors with non-symmorphic space group to search for similar physics." ❍

# Superconductivity Roundup

*Events & Opportunities from Around the Industry*

SW Researchers with **UPMC University Paris**, **Cornell University**, **the University of Rome La Sapienza**, and **the Fondazione Italian Institute of Technology** in Genoa have concluded a **theoretical study** of the magnetic and superconducting properties of electron-doped **$Li_x$HfNCl** (10.1103/PhysRevB.96.024518). The researchers found that at a doping level of x=0.055, the $T_c$ of $Li_x$HfNCl could be as high as 40 K. The study suggests that the synthesis of cleaner samples of $Li_x$HfNCl could remove an Anderson insulating state that competes with superconductivity in the material, resulting in a high-$T_c$ superconductor.

HfNCl is a band insulator that undergoes an insulator to superconductor transition upon doping at around x=0.13. The metallic and

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superconducting phase, $Li_xHfNCl$ is a prototype two-dimensional two-valley electron gas with parabolic bands.

*sw* Researchers at the **Korea Research Institute of Standards and Science** (KRISS) have developed a **SQUID-based MEG device** that can be used to measure the brain and heart signals of small lab animals including mice. The device means that researchers will not have to dissect lab mice to perform some forms of analysis, such as experiments to measure brainwaves.

Previously in order to measure brainwaves the upper part of the skull had to be removed to make room for an electrode. Lab mice are used in 96% of all animal tests.

*sw* **Atos** has developed a **simulation platform** for **programming quantum computers**. The simulator, known as the Atos Quantum Learning Machine (QLM), runs on an ultra-compact supercomputer which the company says is the size of a regular enterprise server. It comes in five power configurations, has 30 to 40 qubits, and is equipped with specific hardware components to accelerate quantum calculations and which can eventually be replaced by quantum accelerators.

The simulator can be programmed in Atos Quantum Assembly Language (aQasm). Although it is currently meant to be used by quantum computing researchers to develop applications and algorithms for the simulator, the hope is that it will eventually be used on quantum computers after they come online. Another intended use is to develop algorithms that canít be decrypted by quantum computers once they are built.

*sw* The **Atmospheric Profiling Synthetic Observation System** (APSOS), an atmospheric observation system that among other instruments includes a terahertz superconducting radiation spectrometer, has **arrived** at its final location at the **Yangbajain cosmic rays monitoring station** in Tibet. APSOS is capable of monitoring the composition of the atmospheric including its temperature, wind, ozone, and carbon dioxide levels through remote sensing.

The system was funded by the National Nature Science Foundation of China in a program launched in 2012. The Yangbajain monitoring station was chosen as the site for APSOS due to its altitude of 4,300 m. The terahertz superconducting radiation spectrometer can only work at altitudes above 3,000 m.

*sw* A **sphere** weighing four grams has been **levitating** in a **superconducting gravimeter** for **8081 days** (22 years and 45 days) in the Royal Observatory of Belgiumís Membach underground lab near Eupen, Belgium. The figure doubles the world record in physics and gravimetry.

The superconducting gravimeter has been measuring gravitational variations for the longest recorded time at a single location. It also represesnts the longest period that an artifact has been levitated in a magnetic field using superconductivity.

The magnetic field field was created in 1995 by injecting currents into superconducting coils, causing the sphere to levitate. The currents have never dissipated since then.

These measurements give access to long-term variations in gravity, which remain little known. These variations are caused by slow tectonic movements or climate change, and are important for the study of the water cycle that influences gravity.

*sw* **Microsoft** and the **University of Copenhagen** have signed **an agreement** under which Microsoft will establish new labs on the universityís site and increase the number of its employees working with Copenhagen researchers on quantum computing. While the specific funding for the project was not announced, it was advertised as a multimillion-dollar investment in new facilities and equipment.

Microsoft also has quantum research sites at Purdue University, Delft University of Technology, and the University of Sydney. In 2012, U Copenhagen opened the Center for Quantum Devices.

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*sw* Researchers with the **Krasnoyarsk Scientific Center at the Russian Academy of Sciences** and **Siberian Federal University** (SFU) in Krasnoyarsk, Russia, have concluded a study of the magnetic properties of **copper oxide nanoparticles** produced via plasmochemical synthesis at various magnetic fields and temperatures (10.1007/s10948-017-4311-2). The researchers hope to use the nanoparticles to synthesize a high-$T_c$ and possibly room temperature superconductor.

Researchers at SFU first synthesized $CuO_2$ nanopowder for potential use in superconductors three years ago. The addition of an oxygen atom to the naturally-occuring CuO compound results in a material with magnetic properties characteristic of superconductors. The research team believes that if the $CuO_2$ particles can be merged into a single material, it is likely to behave like a superconductor at room temperature.

In the recent study, the researchers found that the $CuO_2$ particles existed in a ferromagnetic state at low magnetic field at all temperatures within the studied range. At high magnetic field strength and temperatures under 200 K, the nanoparticles exhibit a paramagnetic state due to the spin-glass behavior of the copper atoms. At high magnetic field strengths above 3 kOe and above 300 K, the nanoparticles were found to enter a diamagnetic state.

*sw* The **Council on Superconductivity** has announced **Federico Scurti** as the **Chair of the CSC Young Professionals**. Scurti is a Ph.D. student in Materials Science and Engineering at North Carolina State University. He is currently developing a quench detection system based on Rayleigh-backscattering interrogated optical fibers and has advanced and demonstrated the concept of a smart conductor that is able to monitor its health as a function of position and time.

*sw* Researchers with the **University of Warwick** and the **Indian Institute of Science Education and Research Bhopal** have concluded a study of the superconducting normal-state properties of the noncentrosymmetric superconductor $Re_6Zr$ (10.1103/PhysRevB.96.064521). Resistivity measurements indicate $Re_6Zr$ has poor metallic behavior and is dominated by disorder. $Re_6Zr$ undergoes a superconducting transition at a $T_c$ $6.75 \pm 0.05$ K. Magnetization measurements give an $H_{c1}$ of $10.3 \pm 0.1$ mT.

The research team approximated that $Re_6Zr$ has an $H_{c2}$ of $11.2 \pm 0.2$ T. Low-temperature specific-heat data suggest that $Re_6Zr$ is an isotropic, fully gapped s-wave superconductor with enhanced electron-phonon coupling.

*sw* Researchers from the **University of New South Wales** (UNSW) have developed a method for creating **non-superconducting 'flip-flopí qubits**. The qubits are made of single atoms that can be spaced farther apart than has been previously possible but still close enough to pack many qubits close together. The capability may help overcome a scalability problem in terms of actually building scalable quantum computers and pave the way for larger spin-based quantum computers.

Qubits based on superconducting circuits are larger and easier to fabricate than flip-flop qubits, but in the long run they may face challenges when trying to assemble and operate millions of qubits. Last year, the Australian government committed AUD$25 million ($19.2 million) over five years to develop a non-superconducting, silicon-based quantum circuit to be built at the Center for Quantum Computation and Communication Technology (CQC2T) at UNSW (see *Superconductor Week*, Vol 30, No 9).

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

~Insert~

October 22, 2017 Vol. 31, No. 8

## Superconductivity Stock Index

| Company Name | Symbol | Prices ending 30-Dec-2016 | Prices ending 29-Sept-2017 | Percentage change |
|---|---|---|---|---|
| American Superconductor | AMSC | 7.37 | 4.54 | -38% |
| Oxford Instruments | OXIG.L | 9.04* | 12.99* | 44% |
| Superconductor Technologies | SCON | 1.23 | 1.03 | -16% |
| Bruker Corporation | BRKR | 21.18 | 29.75 | 40% |
| Furukawa Electric | 5801 | 30.38** | 54.76** | 80% |
| Ion Beam Application | IBAB.BR | 43.82*** | 33.96*** | -23% |
| | | | | |
| Superconductor Index (12/31/14 = 100) | | 100.00 | 140.86 | 41% |
| Standard and Poor's 500 | | 2,238.83 | 2,519.36 | 11% |

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

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

## U.S. Superconductivity Patents

**SC Airbridge Crossover**
International Business Machines Corporation
Apr. 4, 2017
U.S. Patent No. 9614270
A first ground plane, resonator, and second ground plane are formed on a substrate. A first lift-off pattern is formed of a first lift-off resist and a first photoresist. The first photoresist is deposited on the first lift-off resist. A SC sacrificial layer is deposited while using the first lift-off pattern. The first lift-off pattern is removed. A cross-over lift-off pattern is formed of a second lift-off resist and a second photoresist. The second photoresist is deposited on the second lift-off resist. A cross-over SC material is deposited to be formed as the SC airbridge while using the cross-over lift-off pattern. The cross-over lift-off pattern is removed. The SC airbridge is formed to connect the first and second ground planes by removing the SC sacrificial layer underneath the cross-over SC material. The SC airbridge crosses over the resonator.

**MR System Employing a Digital SQUID**
Hypres, Inc.
Apr. 11, 2017
U.S. Patent No. 9618591
A MR system, comprising at least one SQUID, configured to receive a RF electromagnetic signal, in a circuit configured to produce a pulsatile output having a minimum pulse frequency of at least 1 GHz which is analyzed in a processor with respect to a timebase, to generate a digital signal representing MR information. The processor may comprise at least one rapid single flux quantum circuit. The MR information may be image information. A plurality of SQUIDs may be provided, fed by a plurality of antennas in a spatial array, to provide parallel data acquisition. A broadband excitation may be provided to address a range of voxels per excitation cycle.

**Magnet System**
Bruker BioSpin GmbH
Apr. 11, 2017
U.S. Patent No. 9620273
A magnet system has a magnet cryostat housing a first SC magnet coil and a second magnet coil co-

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axial to the first magnet coil. The second magnet coil is short-circuited in a SC persistent mode during operation of the magnet system. An external power supply during operation supplies current to the first magnet coil via a current lead thereby generating a first magnetic field at the sample location that fluctuates according to the current noise of the power supply, wherein the second magnet coil is positioned and dimensioned in a way that it inductively couples to the first magnet coil such that it generates at the sample location a second magnetic field that compensates the fluctuations of the first magnetic field.

**Cyclotron and SC Electromagnet**
Sumitomo Heavy Industries, Ltd.
Apr. 11, 2017
U.S. Patent No. 9622334
A cyclotron includes a pole; a SC coil wound so as to cover an outer periphery of the pole; a coil support that supports the SC coil; a cooling part that cools the SC coil; a first support that is connected to the coil support and is capable of adjusting a position of the coil support in a direction of a winding central axis of the SC coil; and a second support that is connected to the coil support and is capable of adjusting the position of the coil support in an orthogonal direction orthogonal to the direction of the winding central axis of the SC coil. The second support has a link mechanism that is displaceable in each of the direction of the winding central axis and the orthogonal direction.

**SC Devices with Ferromagnetic Barrier Junctions**
Hypres, Inc.
Apr. 18, 2017
U.S. Patent No. 9627045
A SC memory cell has a magnetic Josephson junction (MJJ) with a ferromagnetic material. The binary state of the MJJ manifests itself as a pulse appearing on the output. A SC memory includes an array of memory cells. Each memory cell includes a comparator with at least one MJJ. Selected x and y-directional write lines in their combination can switch the magnetization of the MJJ. A SC device includes a first and a second junction in a stacked configuration. The first junction has an insulating layer barrier, and the second has an insulating layer sandwiched in-between two ferromagnetic layers as barrier.

**Operating a SC Device Without a Shunt System**
Bruker HTS GmbH
Apr. 18, 2017
U.S. Patent No. 9627107
A method for operating a SC device having a coated conductor with a substrate and a quenchable SC film, wherein the coated conductor has a width W and a length L, is characterized in that the coated conductor has an engineering resistivity shunting the SC film in a quenched state. The risk of a burnout of a SC device in case of a quench in its SC film is reduced to such an extent that the device can be operated without use of an additional external shunt.

**Persistent-mode MRI Magnet**
Massachusetts Institute of Technology
Apr. 18, 2017
U.S. Patent No. 9627119
A SC magnet and method for making a SC magnet are presented. The SC magnet is made by forming a coil from windings of a first wire comprising a reacted $MgB_2$ monofilament, filling a cavity of a stainless steel billet with a Mg + B powder. Monofilament ends of the first wire and a similar second wire are sheared at an acute angle and inserted into the billet. A copper plug configured to partially fill the billet cavity is inserted into the billet cavity. A portion of the billet adjacent to the plug and the wires is sealed with a ceramic paste.

**SC, SC Wire, and Method of Forming the SC**
SUNAM CO., LTD.; SNU R&DB FOUNDATION
Apr. 25, 2017
U.S. Patent No. 9,634,223
A SC is formed by a process including a first step of forming liquid-phase rare earth-copper-barium oxide by heat treating a SC precursor including a rare earth element, barium, and copper, a second step of forming a first SC of the rare earth-copper-barium oxide that is epitaxially grown from the liquid-phase rare earth-copper-barium oxide, and a third step of forming a second SC of the rare earth-copper-barium oxide by heat treating the first SC, wherein the heat treatment of the third step is performed in an atmosphere in which the rare earth-copper-barium oxide has no liquid phase.

**Fabrication of SC Circuits**

D-Wave Systems Inc.
Apr. 25, 2017
U.S. Patent No. 9634224
In one aspect, fabricating a SC integrated circuit with a Josephson junction includes applying oxygen or nitrogen to at least part of a structure formed from an outer SC layer to passivate an artifact, if any, left from removing the portion of the outer SC layer. In another aspect, a first SC layer is deposited, a second SC layer is deposited on the first Sc layer, an oxide layer is formed on the first SC layer, a dielectric layer is deposited on the oxide layer, a portion of the dielectric layer is removed, a first portion of the oxide layer is removed, a second oxide portion is formed in place of the first portion of the oxide layer, and a third SC layer is deposited on the dielectric layer and the second oxide portion.

**Magnetic Suspension Planar Motor**
Harbin Institute of Technology
Apr. 25, 2017
U.S. Patent No. 9634540
A magnetic suspension planar motor comprises a structure of SC excitation. A primary base plate is in a shape of board. Armature windings are fixed on an air gap side of the primary base plate. A secondary base plate in a secondary structure is evenly divided into 2 $h^2$ h magnet cells. 2 $h^2$ SC magnets are respectively fixed in the magnet cells on the secondary base plate, which resembles a checkerboard pattern. The SC magnets are adjacent to each other, neither in a horizontal direction nor in a vertical direction. The SC magnets are magnetized parallelly, and magnetization directions of the SC magnets are perpendicular to a surface on an air gap side of the secondary base plate. The SC magnets in a same row or column have same magnetization directions, and the SC magnets in adjacent rows columns have contrary magnetization directions. A cooling container shields all of the SC magnets.

**Discharge Controlled SC Magnet**
May 2, 2017
U.S. Patent No. 9638774
A Cryogen-Free (CF)-type MRI SC magnet system capable of monitoring the conditions of the system components and, in case of a foreseeable quench, discharging the SC magnet at any desired discharge voltage before occurrence of quench.

**HTS Magnet**
General Electric Company
May 2, 2017
U.S. Patent No. 9640308
A HTS magnet coil disposed within a cryostat is configured with a thermo-siphon cooling system containing a liquid cryogen. The cooling system is configured to indirectly conduction cool the HTS magnet coil by nucleate boiling of the liquid cryogen that is circulated by the thermo-siphon in a cooling tube attached to a heat exchanger bonded to the outside surface of the HTS magnet coil. A supply dewar is configured with a re-condenser cryocooler coldhead to recondense boiloff vapors generated during the nucleate boiling process.

**SC DC Reactor**
Industry-Academic Cooperation Foundation
Changwon National University
May 2, 2017
U.S. Patent No. 9640309
A DC reactor consisting of a coil formed of a SC material is provided. It is possible to reduce leakage reactance and to increase critical current by using a coil formed of a HTS material and forming a first bobbin of the DC reactor as a toroid shape.

**Band-shaped SC Element**
Bruker H I S GmbH
May 2, 2017
U.S. Patent No. 9640979
A SC element has a metallic substrate, an insulating layer, a SC layer and a metallic protective layer, wherein the insulating layer is arranged between the substrate and the SC layer. In cross-section of the SC element, the insulating layer extends at both ends past the area ($B_{SL}$) of the substrate covered by the SC layer to galvanically separate the SC layer and the metallic protective layer from the substrate.