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SWJTU Completes Prototype HTS Maglev System

Researchers at Southwest Jiaotong University (SWJTU) have designed and built a prototype HTS maglev vehicle. The engineering prototype has a designated 165-meter test track at SWJTU.

Prototype Developed in Collaboration with CRRC

In 2020, SWJTU entered a collaboration with China Railway Rolling Corporation (CRRC), China Railway Group Limited, and other institutions to manufacture the prototype and test line. Last year, CRRC separately completed a trial run of a different maglev prototype at Shanghai Tongji University.

SWJTU plans to use its maglev system to improve the commercially viability of the technology, a process that they estimate could take as long as six years. The current estimated cost of building a new maglev line in China is between 250 million yuan ($38.65 million) and 300 million yuan ($46.34 million) per kilometer, compared to 200 million yuan ($30.9 million) per kilometer for conventional high-speed rail.

In addition to reducing the system's costs, SWJTU also hopes to reduce the vehicle's noise by improving its' aerodynamics. The research team is planning to construct a much longer experiment track to better test the maglev system's performance.

System Could be Combined with Vacuum Tube Technology

The SWJTU prototype vehicle has a full carbon fiber lightweight body, is based on a low resistance locomotive shape, and incorporates HTS maglev with a large load capacity. It has a design speed of 620 km/h (385 mph). If the maglev system is combined with low vacuum tube technology in the future, its design speed could rise up to 800 km/h (497 mph).

SWJTU is separately developing a HTS megathermal maglev loop line using a vacuum tube design, dubbed super-maglev (see *Superconductor Week*, Vol 28, No 6). The use of the vacuum tube decreases the speed limitations imposed by air resistance on regular maglev trains and reduces the noise they generate.

For a maglev train at a running speed of 400 km/h (250 mph), 83% of traction energy is dissipated in air resistance. However, aerodynamic noise for such a train is over 90 dB, higher than the environmental standard of 75 dB.

‣ The first set of tests on the HTS maglev ring system was completed in March 2013. They were conducted without an enclosed vacuum tube around the track.

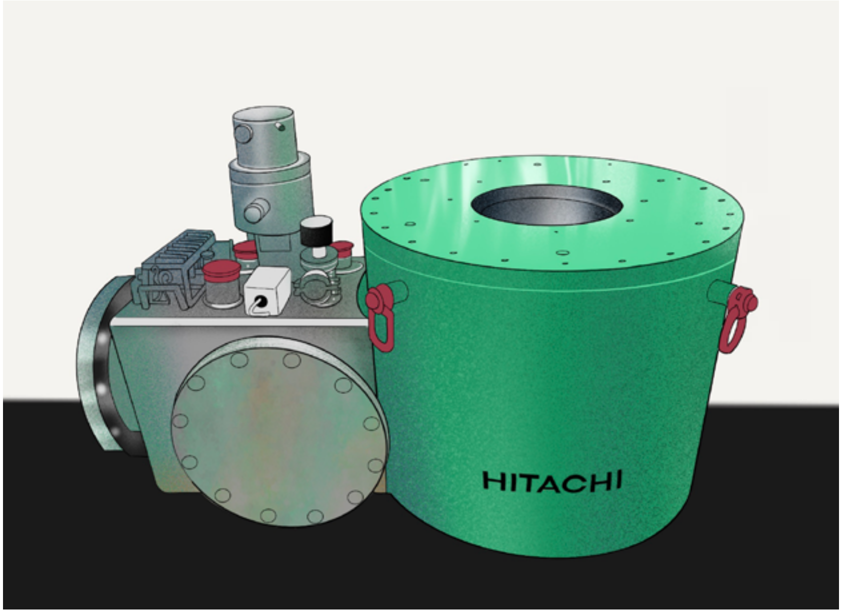
SJU has since enclosed the 12-meter diameter circular test track in an evacuation tube. The system is intended to enable the prototype to reach a maximum speed of 50 km/h (30 mph) without passengers.

Non-SC Maglev Line Opened in Shanghai in 2003

China's first commercial maglev system, Shanghai Transrapid, was put into operation in 2003. The 30-km (19-mile) line between downtown Shanghai and the city's Pudong airport carried its millionth passenger in 2004 (see *Superconductor Week*, Vol 18, No 8). The line is based on non-superconducting electromagnetic suspension maglev technology and has a maximum speed of 430 km/h (267 mph).

A maglev line featuring superconducting technology that operates at 500 km/h (311 mph) is expected to open in Japan in 2027, running between Tokyo and Nagoya (see *Superconductor Week*, Vol 27, No 10). That project has a total cost estimated of 1 trillion yen ($1.2 billion).

The L0 trains to be used on the Tokyo-Nagoya line use a LTS niobium-titanium alloy for the superconducting maglev in the vehicles, unlike the HTS prototype unveiled by SWTJU. During previous tests of the L0 train concluded in 2011, the train achieved the world's highest speed for a train at 581.7 km/h (361.5 mph), was run a distance of 2,876 km (1,787 miles) in a day, and was used in passing tests with a relative speed of 1026.3 km/h (637.7 mph)(see *Superconductor Week*, Vol 25, No 23). ■



Hitachi Creates Superconducting MgB_2 Klystron Magnet

Hitachi, Ltd., has developed, produced, and tested a superconducting magnet made with magnesium diboride (MgB_2) coils, and have reported uniform I_c properties through an 8.0 km wire (doi:10.1109/TASC.2020.2970391). The magnet has been delivered to Japan's High Energy Accelerator Research Organization (KEK) for future use by CERN in a klystron, a microwave generator, in an accelerator system where it will be used to focus electron beams.

A klystron is a specialized linear-beam vacuum tube that is used as an amplifier for high radio frequencies from UHF up into the microwave range. In a klystron, an electron beam interacts with radio waves as it passes through resonant cavities along the length of a tube.

The electron beam first passes through a cavity to which the input signal is applied. The energy of the electron beam amplifies the signal, which is taken from a cavity at the other end of the tube.

Klystrons can produce far higher microwave power outputs than solid state microwave devices. They have many uses, including for radar, satellite and wideband high-power communication, radiation oncology, and in high energy physics for particle accelerators and experimental reactors.

MgB_2 Magnet Provides Better Performance with Reduced Power Consumption

CERN's klystron currently uses water-cooled copper coils. The Hitachi prototype magnet has demonstrated a major reduction in power consumption and a notable improvement in klystron efficiency, reducing its power consumption to one-seventh or less of its current value. The MgB_2magnet is capable of generating a 0.8 T magnetic field when powered at its rated value of 57.1 A, with the coil cooled to about 20 K by conduction cooling.

Researcher Hideki Tanaka of Hitachi's Center for Technology Innovation – Energy, who led the klystron magnet initiative, commented on the interest his company has in superconducting MgB_2 wire applications: "We think the MgB_2 wires have the potential to be produced at a lower cost than HTS conductors. They can be made as round shape and multifilament wires."

Various Tests Showed I_C Uniformity

Hitachi manufactured a total of 8.0 km of MgB_2 wire using a typical in situ method. The wire has 10 filaments and is 0.67 mm in outer diameter. The magnet was made from two separate coils of 2.9 km that were wound using the Wind & React method. The appropriate length was calculated from the magnetic field distribution for the beam focus within the klystron.

Tanaka explained that in fabricating the wire, one major challenge was reducing the heat penetration from the RT to the superconducting coils: "The power consumption to maintain the temperature of MgB_2 coils is equal to the heat penetration from outside to the inside of the magnet. Most of the heat penetration is via the current leads from RT to the coils. Therefore, we had to use thinner power-leads."

The Hitachi researchers evaluated the wire through several methods and found that the I_C properties of the entire wire length are quite uniform. Testing short wire samples revealed very little deviation of I_C values. In addition, the current sharing temperature of the MgB_2 magnet, made from the two reels of 2.9 km-long wire, was consistent with the estimated value of the I_C -B-T properties in short sample wires. ■

FRA Issues Review of DC-Baltimore Superconducting Maglev Line

The U.S. Federal Railroad Administration (FRA) has issued a draft environmental impact statement of a proposed 40-mile superconducting maglev line that will carry passengers between Washington, DC and Baltimore in 15 minutes at 311 mph. The review considers potential routes, as well as economic and environmental impacts.

The project is considered to be the first phase of a system that would eventually move travelers between Washington and New York City in an hour. Federal approval might be given later this year, in which case the system could be built over the coming decade.

According to the FRA report, the project would cost between $13.8 billion and $16.8 billion, depending on the alignment chosen, which is higher than previous estimates. Northeast Maglev, the private organization promoting the project, had calculated costs at between $10 billion and $12 billion.

The group has reportedly received a $5 billion financing commitment through the Japan Bank for International Cooperation. The remaining funds would have to be raised from public and private sources, which might include U.S. government loans and grants. In 2016, the FRA awarded $27.8 million to Maryland for preliminary engineering and environmental studies for the project (see *Superconductor Week*, Vol 29, No 11).

Project to Use JR Central Technology

The superconducting maglev technology to be used has been tested by the Central Japan Railway Company (JR Central) on its 27-mile-long Yamanashi maglev line, the experimental track for the Tokyo-Nagoya superconducting maglev line that is to be completed in 2027 (see *Superconductor Week*, Vol 27, No 10). During a trade mission to Japan in 2015, Maryland Governor Larry Hogan and Japanese Prime Minister Shinzo Abe agreed on a Memorandum of Cooperation between the State of Maryland and the Government of Japan that included high-speed superconducting maglev rail as a specific area of

▸ cooperation (see *Superconductor Week*, Vol 29, No 11). JR Central has announced that it will not charge any licensing fees for the technology.

The FRA noted that congestion levels, projected population growth, and economic power made the Washington - Baltimore corridor attractive for this type of project. Existing transit between the two cities, Amtrak's train service, MARC commuter trains, and buses, have become unreliable due to aging infrastructure and a saturated rail and highway system. The agency expected that capacity would continue to worsen as the demand on existing infrastructure increased, and concluded that the maglev project would supplement other planned and programmed projects and help alleviate transportation concerns in the region

Two Routes and Six Construction Alternatives Analyzed

Two potential routes are under consideration, both parallel to the Baltimore-Washington Parkway, and that would tunnel beneath the towns of Bladensburg, Greenbelt, Laurel and Linthicum. Six construction alternatives are addressed for the two alignments, both east and west of the Parkway.

On the west side, the rail line would track along the edge of the highway right of way and affect some residential properties. On the east side, the route would cross federal lands, including the Parkway, the National Security Agency at Fort Meade and NASA in Greenbelt, the preferred option for Northeast Maglev officials. The train would run underground for much of its route in a single tunnel of 43 feet in diameter that would carry two guideways and be built using a tunnel boring machine at 80 feet to 170 feet below the surface.

With any of the options, the line would have stations at Mount Vernon Square in Washington, at Baltimore-Washington International Marshall Airport, and in the Cherry Hill neighborhood of Baltimore. The FRA report states the project would create between 161,000 and 195,000 jobs during a seven-year construction period and generate between $8.8 billion and $10.6 billion of potential earnings for employees. Once built, the line could support between 390 and 440 jobs annually, and between $24.3 million and $27.4 million of earnings for workers, with additional benefits to property values near the proposed stations in Washington and Baltimore.

Opposition Emerges from Communities Along the Route

However construction would have some negative consequences for communities along the line that would experience construction-related disruptions. The FRA reports estimates the cost of these disruptions as ranging from $18.5 million to $311.3 million due to lane closures, traffic delays, and limited accessibility that would reduce the number of people frequenting the area and supporting businesses.

The travel cost on the maglev line would be higher than on existing modes of transportation. According to the FRA, the expected average fare would be $60 for a one-way trip, although this could vary between $27 and $80 per trip. Amtrak's Acela costs $46 one-way for a 32-minute trip, while hour-long ride on a MARC commuter train costs $8.

The cost disparity has led critics to decry the project as disproportionately benefiting the wealthy while having little positive effect on the communities between Washington and Baltimore where the train will not stop. However, required emergency exits in locations along the line will necessitate drilling as deep as 150 feet.

Residents along the route are concerned about potential vibration as well as the impact on property values and parkland along the project's path. One critic sent a letter to the Washington Post, suggesting that locating the line farther west along the Interstate 95 freeway corridor would be more appropriate since much of the line could be routed through industrial areas.

The release of the report triggered a 90-day comment period on the document that began on January 22 and will end on April 22. The FRA will also hold virtual public hearings. ■

Fermilab Leads U.S. Quantum Computing Initiative

The Fermi National Accelerator Lab (Fermilab) recently launched its Superconducting Quantum Materials and Systems Center (SQMS), a state-of-the-art research center focused on furthering quantum innovation. The U.S. Department of Enegy has committed $115 million over five years to the program.

"SQMS is one of five Centers funded by the Department of Energy under the authority of the National Quantum Initiative (NQI)," said Jim Sauls, deputy director of the SQMS center. "SQMS is unique in its focus on developing beyond state-of-the-art quantum computers based on superconducting microwave cavity technology from Fermilab and superconducting quantum device technologies perfected at Rigetti Computing and NIST Boulder."

Fermilab has a history of building and perfecting superconducting radio frequency (SRF) cavities for particle accelerators. "These machines are key to accelerator-based studies of fundamental physics," pointed out Sauls. "These same SRF cavities have performance characteristics that make them a frontier technology for quantum computing and sensing."

National Quantum Initiative to Develop State-of-the-art Quantum Computer

The aim of NQI is to fabricate and deploy a state-of-the-art quantum computer utilizing superconducting technology. Another objective is the development of new quantum sensors to aid in the search for dark matter and other subatomic particles.

SQMS will spearhead a broad multidisciplinary collaboration of 20 partners, which include other national labs, universities, and industry. Team members will focus on different aspects of quantum information research, with various participants researching qubit quality limitations at the nanometer scale, fabrication and scale-up capabilities into multiqubit quantum computers, and the exploration of new applications of quantum computing systems.

"Fermilab is a world leader in developing SRF cavities," asserted Sauls. "This technology is a key driver for the SQMS mission to build beyond state-of-the-art quantum processors, as well as sensors for searching for dark matter candidates. Rigetti has state-of-the-art fabrication facilities for superconducting qubits for quantum processors, while Ames Lab and Northwestern University host world-class materials characterization facilities that will be central to identifying and mitigating sources of decoherence that degrade the performance of both microwave cavities and superconducting qubits."

Maintaining Qubit Coherence is Key Initiative

One central aspect of SQMS research is centered around the duration that a qubit is able to maintain coherence, which is analogous to better understanding and mitigating sources of decoherence in quantum devices, a key requisite to the design and production of tomorrow's quantum computing systems. Fermilab already boasts the world leading coherence times in their superconducting cavities, designed for particle accelerators, and now the program is being expanded to incorporate quantum qubits.

"The integration of superconducting qubits with high Q microwave SRF cavities is one of the key directions for the development of 3D quantum processors," Sauls indicated. "Preliminary studies at Fermilab show this to be a promising direction. The key is to maintain the long lifetime of microwave photons in the cavity with the qubit coupled to the cavity field."

Previously, Fermilab demonstrated that a single microwave photon can live for several seconds within an SRF cavity. Said Sauls of the accomplishment: "This is a breakthrough achievement in the lifetime of a photon confined in a microwave cavity, and it enables a new generation of quantum devices for both computing and sensing technologies."

Coherence is essential for qubit longevity and interconnection, key elements for a high-functionality quantum computing system able to conduct a wide range of applications. In this vein, SQMS is launching a materials-science study into the limiting mechanisms of cavities and qubits to better understand quantum properties of superconductors and other materials as they pertain to the nanoscale and microwave regime.

"SQMS is initially looking to limit losses on the substrates and interfaces that are present in fabricated transmon qubits," said Sauls. "So we are looking at he atomic scale with a host of materials science tools to identify sources that lead to decoherence. In this tcontext 'other materials' refers to materials to passivate surfaces to limit oxidation and the formation of local defects that degrade qubit performance."

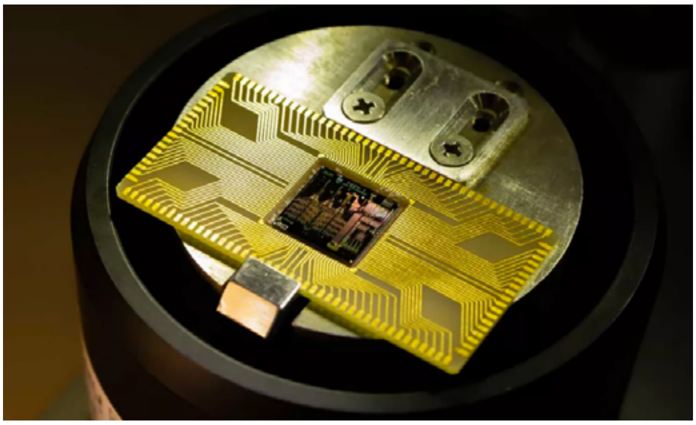
Six Partners to Coordinate Decoherence Effort

Northwestern, Ames, Fermilab, Rigetti Computing, the NIST, and the Italian National Institute of Physics (INFN) are all united in this decoherence effort. Rigetti Computing will be fabricating qubits and full stack quantum computing capabilities required for the SQMS quantum computer. The NASA Ames Research Center quantum group contributing with programs investigating quantum algorithms, programming, and simulation. The INFN has research programs centered around detector development, cryogenics and environmental measurements, and the worlds largest underground facility.

"Our approach is a parallel track of improving 2D quantum processors utilizing the expertise from Rigetti in building full-stack quantum computers, and integrating transmon qubits with SRF cavities to develop a new generation of 3D quantum processors utilizing the multi-mode photon states of these high Q SRF cavities," Sauls explained. " A strength of Fermilab is the experience in large scale integration of cryogenic and microwave technologies, and in Rigetti's experience and facilities for building superconducting transmons and 2D quantum processors."

Sauls noted that Fermilab aims to deliver the next generation of quantum processors based on 2D architectures and qubits with longer coherence times in three years, and beyond state-of-the-art quantum computers based on 3D architectures in five years: "There is a great deal of basic research that will be carried out within SQMS to reach these goals, and that knowledge will also inform the direction of research and development of quantum devices and sensors. In terms of quantum sensing, short of discovering dark matter, we expect major new limits to be set for two dark matter candidates using SRF cavities as quantum sensors for detection of the dark matter candidates, the axion and dark photon." ■

YNU Pioneers Superconducting 4-bit Adiabatic Processor



The MANA microprocessor composed of over 20,000 superconductor Josephson junctions implemented in adiabatic quantum-flux-parametron (AQFP) logic. It is the world's first adiabatic superconductor microprocessor.

Researchers from Yokohama National University (YNU) have successfully demonstrated a prototype microprocessor that uses superconducting niobium, the first time an adiabatic superconductor microprocessor has ever been demonstrated. (DOI: 10.1109/JSSC.2020.3041338). Their novel device delivers a significant increase in energy efficiency compared to the semiconductor microprocessors that are commonly used today, which suggests that they might be suitable in applications in large data processing centers.

Computation power is currently responsible for about 10% of global energy consumption. If improvements are not made on communications infrastructure or the electronics that drive communications networks, this figure could climb to 50% by 2030. With an ever increasing demand for computational power and the energy to power it, the coming years will surely see great demand for and potential benefit from technologies improving data transmission efficiency.

Device is Built into an AQFP Structure

The Yokohama 4-bit processor, dubbed the Monolithic Adiabatic iNtegration Architecture (MANA), is based on unshunted Josephson junction devices built into a superconducting digital electronic structure called an Adiabatic-Quantum-Flux-Parametron (AQFP) for a hybrid Reduced Instruction Set Computer (RISC) data flow machine. A RISC is essentially a computer with a smaller set of instructions optimized with a large number of registers and a regular instruction pipeline, which makes for greater computing power with a lower number of clock cycles per instruction - the clock rate refers to the frequency at which the clock generator of a processor can generate pulses and is used to gauge processing speed.

"The microprocessor is manufactured using a fabrication process that consists of four niobium superconductor layers with Nb/AlOx/Nb Josephson junctions," commented YNU associate professor Christopher Ayala. "The process is called the high-speed standard process (HSTP) and has a critical current density of 10 kA/cm^2. It is provided by the Clean Room for Analog-digital superconductiVITY (CRAVITY) at the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan."

The team catered their architectural design specifically for AQFP logic. They opted for RISC architecture because the pipeline is straightforward, easy to implement, and well understood in the microprocessor community. However, the clocking setup allowed propagation of data through only four levels of logic gates per clock cycle, which required the researchers to introduce dataflow architecture techniques such as embedding program control signals in each instruction so that the microprocessor could quickly make program flow decisions.

The microprocessor has a core set of 25 instructions covering program branching, logic, and arithmetic operations, as well as input/output operations. Data word size was restricted on the prototype to 4-bit in order to study the system at a smaller scale and understand what challenges would need to be addressed before scaling it up.

MANA Processor Employs Over 10,000 AQFPs

An AQFP is a logic primitive composed of a few fast-acting Josephson junctions, which require minuscule amounts of energy to support superconducting electronics. The MANA processor is made up of over 20,000 Josephson junctions, or over 10,000 AQFPs, which come in several varieties.

"The standard [AQFP] design behaves like a clocked buffer," indicated Ayala. "A small tweak of the output transformer by negating the coupling factor yields a clocked inverter and introducing some small asymmetries to the standard design gives us a constant logic '1' and logic '0' cells.

"By mixing and matching these variations and tying their outputs together through an inductor network, we can create a rich set of majority-logic based Boolean logic gates. We also have other more significant variations of the AQFP including a version with improved input sensitivity to be used as a comparator for SNSPD applications."

Each AQFP has a large output transformer that uses most of the structure's already large 20 µm x 40 µm footprint. The clocking scheme is four-phase, where each AQFP logic gate is clocked by one of the four available phases from the power-clock network. This requires that gates placed on the chip must in a specific physical row designated by their assigned clock phase.

"The power-clock network is a serial biasing scheme which creates unwanted clock skew that we need to consider as the power-clock network meanders throughout the chip," Ayala said. "We need to constrain the clock skew by dividing the power-clock network into smaller sections via microwave power dividers such as a Wilkinson or a simple resistor-based power divider.

"Also, the parasitic inductances of the superconductor stripline interconnects attenuates the data signal currents, so the AQFPs have limitations on how far they can be connected, up to about 0.7 to 1.0 mm. With the large size of the AQFP, the placement restrictions of the power-clock network and its intrinsic clock skew, and the limited interconnection lengths between AQFPs, it is not easy to get an area efficient layout. So, in addition to careful manual placement of our logic cells, we developed a placer tool based on the genetic algorithm to help find good placement solutions."

Second Chip Tested with 2.5 GHz Clock Frequency

The prototype demonstrated functionality in register file R/W access, ALU execution, hardware stalling,

▸ and program branching and was especially adept at data processing. "The prototype was designed using a 1 cm x 1 cm chip," expanded Ayala. "At the start of this project, we thought a 7 mm x 7 mm chip was sufficient; we have a high-speed helium immersion cryoprobe that can accept a 7 mm x 7 mm chip for high-speed testing. Over time, we began to realize that our AQFP circuits need more chip area than expected.

"This was especially true for our register file which takes up most of the chip area. We had to switch to a larger 1 cm x 1 cm chip and limit our testing to low frequency (100 kHz) using a low speed cryoprobe in liquid helium. The power-clock network is provided from two sinusoidal AC signals with an amplitude of 0.9 mA coupled with a dc offset of 1.2 mA. We loaded four instructions at a time into the microprocessor from an input generator and observed the outputs tapped from the results written to the register file via dc-SQUID readout circuits.'

The researchers had wanted to demonstrate that at least some part of microprocessor could run at GHz-range clock frequencies so they placed the execution stage consisting of the ALU and data shifter, on a separate 7 mm x 7 mm chip in order to conduct high-speed testing with the high-speed cryoprobe. They were able to operate the chip up to 2.5 GHz, which required a special high-speed dc-SQUID stack voltage driver interface to observe the high-speed output. They surmised that the 2.5 GHz limitation was either due to the output interfaces or the experimental setup, and not necessarily a problem of the AQFP circuits themselves.

"We hope to show at least 5 GHz operation as we continue to improve the output voltage driver interface and the experimental setup," Ayala said. "To reach 10 GHz, we need to use larger microwave power dividers and reduce the size of the local meandering of the power-clock networks to reduce the clock skew. As we work towards developing more compact AQFP cells and developing new clocking schemes beyond our four-phase approach, we believe we can reach 10 GHz."

Microprocessor 80 Times More Efficient than Current Models

At an operating temperature of 4.2 K, the energy demands for cryogenics might have been expected to outweigh the improved energy efficiency. Yet even after factoring in the cryogenics, the microprocessor was demonstrated to be 80 times more efficient than conventional equivalents. The 4-bit superconducting microprocessor doesn't outperform 64-bit processors today, but if scaled up, the researchers believe this would be the case.

Since the circuits are quasi-adiabatic, the switching energy is not fixed, but is dependent on clock frequency or, more specifically, the rise time of the power-clock. Energy optimization was achieved with low switching energy of 1.4 zJ for each Josephson junction, which is significantly lower than in semiconductor devices.

The 1.4 zJ switching energy was present when driven by a four-phase 5-GHz sinusoidal AC-clock at 4.2 K. Decrease the operating frequency also decreased the switching energy, while increasing the frequency increased the switching energy. According to the simulations, this relationship remains mostly linear until about 10 GHz.

"The AQFPs used to build the microprocessor have been optimized to operate adiabatically such that the energy drawn from the power supply can be recovered, in principle, under relatively low clock frequencies up to around 10 GHz, which is low compared to the 100s of GHz typically found in conventional superconductor electronics," clarified Ayala. "We use sinusoidal AC-clocks which provide both the power and synchronization mechanism for the AQFP.

"The clocks are generated in four phases in quadrature, each shifted by 90°, and each AQFP is clocked by one of the four phases. Data propagates from one phase to the next. This means we can only propagate through four levels of logic in a single cycle, which is a major challenge in microprocessor design."

Further Plans to Develop More Compact AQFP Devices

According to Ayala, the operation of the MANA demonstrates that AQFP technology can provide a foundation for building adiabatic computing hardware that is extremely energy efficient coupled with practical computing performance suitable for future high-performance data centers, supercomputers, and other large-scale computing infrastructures. The technology suggests a path towards high-performance computing that benefits from low-energy adiabatic operation. Adiabatic circuits in the semiconductor field can only operate in the kHz to MHz range, which have reasonable applications for mobile applications and sensors where high-clock rates may not be necessary.

"We are now focusing our efforts on improving the technology including the development of more compact AQFP devices, increasing the operation speed, and increasing the energy-efficiency even further through logically and physically reversible computation," said Ayala. "We are also scaling our design methodology so that we can fit as many devices as possible on a single chip and operate all of them reliably at high clock frequencies approaching 10 GHz.

"Our current four-phase clocking approach severely limits us to four levels of logic per cycle which creates large computation latencies in a microprocessor. We are now aggressively pursuing novel clocking methods to substantially improve the latency without impacting the switching energy.

"We also see that the AQFP is suitable for performing new ways of computation including applications in AI hardware and quantum computing. Much further down the line, our ultimate goal is to establish AQFP technology as a versatile electronics foundation for future data centers, supercomputers and communication networks that support many applications including social media, digital content platforms, AI, scientific computing, and quantum computing."

Funding for this work was provided by the Grant-in-Aid for Scientific Research under grant no. 19H05614 and the Grant-in-Aid for Early Career Scientists from the Japan Society for the Promotion of Science under grant no. 18K13801. ■

NIST, UC Boulder Demonstrate TLS Thermometer

Researchers with the National Institute of Standards and Technology (NIST) and the University of Colorado, Boulder, have developed a compact superconducting microresonator thermometer based on two-level systems (TLSs) that is drop-in compatible with cryogenic microwave systems (doi.org/10.1063/5.0029351). The team demonstrated the practical use of the TLS thermometers to investigate static and transient chip heating in a kinetic inductance traveling-wave parametric amplifier operated with a strong pump tone.

TLS thermometry may find broad application in cryogenic microwave devices such as superconducting qubits and detectors. In particular, the devices could be useful in monitoring the temperature of processor chips in superconductor-based quantum computers.

"The thermometer allows researchers to measure the temperature of a wide range of components in their test packages at very little cost and without introducing a large number of additional electrical connections," said NIST and UC Boulder researcher Joel Ullom. "This has the potential to benefit researchers working in quantum computing or using low-temperature sensors in a wide range of fields."

Device Spun off NIST's MKID Sensors

The technology is a spinoff of NIST's custom superconducting sensors for telescope cameras, specifically microwave detectors delivered for the Balloon-borne Large-Aperture Submillimeter Telescope (BLAST). BLAST is a suborbital platform that deploys microwave kinetic inductance detectors (MKID) to measure the polarized thermal emissions of interstellar dust. The TLS thermometer developed in the recent study is smaller, faster and more convenient than conventional cryogenic thermometers for chip-scale devices.

The operational temperature range of the TLS thermometer demonstrated in the recent study is 50 to 1000 mK and may be extendable to 5 mK. The device exhibits a sensitivity of 50 to 75 μK/√Hz that is relatively uniform across the operational temperature range.

Thermometer Incorporates Nb Resonator Coated with SiO_2

The thermometer consists of a superconducting niobium resonator coated with silicon dioxide. The coating interacts with the resonator to shift the frequency at which it naturally vibrates. Scientists suspect this is due to atoms "tunneling" between two sites, a quantum-mechanical effect.

The thermometer is only 2.5 x 1.15 mm in size, and can be embedded in or stuck to another cryogenic microwave device to measure its temperature when mounted on a chip. The device also requires no additional thermometry wiring or readout electronics.

The NIST thermometer is based on a new application of the principle that the natural frequency of the resonator depends on the temperature. It maps changes in frequency, as measured by electronics, to a temperature.

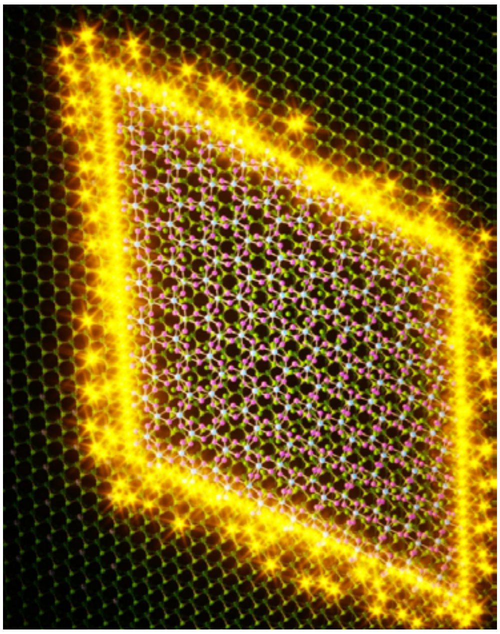
By contrast, conventional thermometers for sub-Kelvin temperatures are based on electrical resistance. They require wiring routed to room-temperature electronics, adding complexity and potentially causing heating and interference.

New TLS Thermometer Faster than Conventional Variants

The NIST thermometer measures temperature in about 5 ms, much faster than most conventional resistive thermometers at about one-tenth of a second. It is also easy to fabricate in only a single process step.

The new thermometer can be mass-produced, with more than 1,200 fitting on a 3-inch (approximately 75-mm) silicon wafer. The researchers used the thermometer to demonstrate fast, accurate measurements of the heating of a superconducting microwave amplifier. ■

Aalto Observes Topological Superconductivity in 2D System



Majorana Zero Energy Modes found at the edge of 2D topological superconductors.
Credit:
Alex Tokarev,
Ella Maru
Studio Aalto University

Researchers at Aalto University, Poland's Marie Curie-Skłodowska University, and Tampere University have designed a material that combines a 2D ferromagnet with a superconductor (doi.org/10.1038/s41586-020-2989-y). They observed 2D topological superconductivity along with evidence of Majorana zero energy modes (MZMs). The system may offer a path towards developing topical quantum computing.

Aalto physics professor Peter Liljeroth, who co-authored the paper, provided some background on the research: "We are working on designer materials based on 2D van der Waals heterostructures. The idea there is that it is possible to combine materials with very different, or even contradictory, properties – such as 2D magnets and 2D superconductors – in a heterostructure where we have controlled interactions between the components that can still retain their intrinsic properties. The exotic properties (e.g. MZMs) arise from the interaction between the layers."

MZMs a Means for Creating Topological Qubits

While the concept of a quantum computer running on topological qubits may lead to advances in the field of quantum information science, researchers have been unable to produce such qubits in a lab setting. Microsoft, working with the University of Copenhagen, has invested for years in the technology, but progress has been slow.

MZMs are electrons bound together in a way that mimics the theorized behavior of a Majorana fermion, a particle which is

▸ its own antiparticle and has been theorized to be the missing element for topological quantum computing systems. Researchers believe that improved topological qubits devised with 1D MZMs could be dramatically more resistant to noise factors that can cause qubit decoherence. To date, however, Majorana fermions remain theoretical and have yet to be produced or directly observed.

"In contrast to their particle physics counterparts, MZMs in condensed matter physics are zero energy, chargeless, spinless, composite quasiparticles, residing at the boundaries of so-called topological superconductors," Liljeroth noted. "Topological superconductors are without exception accompanied by gapless surface/edge modes because of the bulk-edge correspondence of topological systems. These boundary modes can be observed as in-gap states in the quasiparticle density of states of a superconductor.

"In our case, we can directly probe them using scanning tunneling microscopy and spectroscopy. This allows us to test both the expected spectroscopic properties, the density of states as a function of energy, and also to probe where in real space these modes are located, by measuring the local density of states."

Realizing MZMs in a Solid State Platform

To make MZMs, the Aalto-led team gave electrons a specific amount of energy and then trapped them together. This was done on ultra-thin 2D films, but in order to create 1D MZMs, the group had to create a topological superconductor at the boundary of a magnetic electrical insulator and a superconductor. The team focused on 1D MZMs because they could be realized in a 2D platform, which would be relatively easy to fabricate and to control.

Trapping electrons on a topological superconductor is not without its engineering hurdles, however. In order to achieve MZMs, some level of interaction between magnetism and superconductivity is required, without the former disrupting the latter. With 2D materials the process becomes more feasible; there is enough interaction to spur the creation of MZMs but not enough to disrupt superconductivity.

Electron spin is at the root of the disruption; in a magnetic material, electron spin is aligned, whereas in a superconductor the spins are inversely aligned with alternating spin directions. Typically, magnetism will distrust the inverse alignment of electrons in a superconducting state. With a 2D layered material, there is just enough play between the forces to tilt the spins of the atoms sufficiently to exhibit Rashba spin-orbit coupling, an interaction necessary for MZMs.

More Exotic P-wave Pairing Required

"To realize MZMs in a solid-state platform requires that the pairing mechanism between the Cooper pairs in the superconductor is not the usual so-called s-wave pairing," explained Aalto researcher Shawulienu Kezilebieke, the lead author of the paper. "Instead, we would need a more exotic pairing in which electrons with the same spin form a Cooper pair and condense, giving rise to so-called p-wave or triplet superconductivity.

"However, such a pairing is exceedingly rare in nature. The essential ingredient for realizing it artificially is to combine spin-nondegenerate metal and proximity-induced s-wave superconductivity. In this scheme, the spin-orbit coupling lifts the spin-degeneracy of the conduction band, while Zeeman splitting due to proximity magnetization lifts the remaining Kramers degeneracy. Adding superconductivity opens gaps at the Fermi energy and, depending on the magnitude of the magnetization, induced gap and the position of the Fermi energy, the system enters a topological phase."

For this purpose, the researchers elected to use a thin layer of 2D chromium tribromide for their topological superconductor. Chromium tribromide is able to exhibit magnetism in a layer only one atom thick. This ultra-thin layer was grown atop of a niobium diselenide crystal.

"We needed a layered (van der Waals material) ferromagnet and superconductor," added Kezilebieke. "The ferromagnetic layer needed to have a certain out-of-plane magnetization direction.

"Finally, we need to be able to grow these samples in a very clean way. To achieve this, we have used the molecular beam epitaxy (MBE) method to fabricate our heterostructures. Not all 2D ferromagnets are suitable for MBE growth. "

Team Will Seek to Fabricate Topological Qubits

After extensive computer modeling, the team used low-temperature scanning tunneling microscopy and spectroscopy, which revealed the signatures of 1D

▸ Majorana edge modes. Future work will involve designing experiments to understand how the van der Waals heterostructures can be integrated into device structures, and how 1D MZMs can be used to make topological qubits.

"Other research groups (e.g., the Kouwenhoven group from Delft) have tried to make so-called topological qubits using 1D nanowires, which have MZMs at their ends (that is, 0D MZMs)," said Liljeroth. "This is at the level of a well-developed idea, but has not yet been fully demonstrated experimentally.

"We have made 2D topological superconductors which have 1D MZMs circulating them. It is our future outlook to think about how to use these 1D MZMs to make topological qubits.

"Despite the intense academic and commercial interest, the systems that are hosting MZMs are limited. Furthermore, it has proven to be very difficult to create suitable experimental platforms to realize MZMs. Making MZMs in 2D materials offers broad tuneability of the materials properties, high flexibility in fabrication pathways, and the ability to detect and manipulate MZMs in a controlled laboratory setting."

Funding for this research was provided by the European Research Council (ERC-2017-AdG no. 788185 "Artificial Designer Materials"), Academy of Finland (Academy professor funding no. 318995 and 320555, and Academy postdoctoral researcher no. 309975), and the Aalto University Center for Quantum Engineering (Aalto CQE). ■

International Team Discovers G-Wave Superconductors

Researchers at Cornell University, the National High Magnetic Field Lab, the Max Planck Institute for Chemical Physics of Solids, and Japan's National Institute for Materials Science have discovered a new type of superconductor while investigating strontium ruthenate (Sr_2Ru0_4) for spin-triplet superconductivity (doi.org/10.1038/s41567-020-1032-4). Using resonant ultrasound spectroscopy, they observed thermodynamic discontinuity indicating that the superconducting order parameter is two-component, necessitating a new classification, which they designated as "g-wave". This discovery opens the door to an entirely new area of research.

The vast majority of superconducting materials can be classified as s-wave, which are typically found with conventional alloys such as lead, tin, and mercury. In s-wave superconductors, the electrons in each Cooper pair point in opposite directions, and the Cooper pair has no angular momentum.

Electrons may be oriented in any direction. In heavy metals, the spin direction may be fixed. This is due to spin-orbit coupling, and is a property of the normal metal state that gets imposed on the superconductivity.

D-wave and p-wave Superconductors Display Angular Momentum

D-wave superconductors were discovered later and are found in more exotic materials. Here, Cooper pairs have two quanta of angular momentum, only double the smallest angular momentum an object could have.

In the vast majority of d-wave superconductors, the pairs are in a state where an angular momentum of +2 is added with an angular momentum of -2, so the pairs carry no net angular momentum. This keeps the electrons apart, thereby avoiding energy loss, and allows for higher temperature superconductivity. Both s- and d-wave superconductors have spin-singlet Cooper pairs with spin-up/spin-down electrons.

Physicists have proposed a third category of p-wave superconductors. They theorize that a p-wave superconductor would exhibit 'spin-triplet' electrons, in which the paired electrons spin in the same direction, with parallel, rather than anti-parallel spins.

P-wave superconductors are predicted to exhibit one quanta of angular momentum, placing them between s- and d-wave superconductors. If discovered, p-wave superconductors might benefit quantum computing development, since theorists predict they could be used to generate Majorana fermions.

Ultrasound Spectroscopy Conducted at 1.4 K

Sr_2Ru0_4 has been considered a strong candidate for p-wave superconductivity, and the team set out to investigate its properties. When asked how p-wave superconductivity would be identified, researcher Richard Hicks of Max Planck said the electrons would appear "much like in a d-wave superconductor. The angular momentum keeps them apart, but, in practice, p-wave states seem to be very rare, and would not to have high transition temperatures."

The researchers employed resonant ultrasound spectroscopy to examine the symmetry properties of superconductivity in a crystal Sr_2Ru0_4, grown and precision-cut by collaborators at Max Planck. In order to perform the experiment, the Cornell team had to fabricate new equipment that would allow them to cool down the resonant ultrasound to 1.4 K, which set a record for the highest-precision ultrasound spectroscopy ever taken at these temperatures.

"The sample is held by its corners," Hicks said. "You shake one of the corners; if you hit a resonance frequency, the crystal rings, and you can detect a large amplitude of vibration at the other corner. It's like hitting a glass and hearing it ring, although because the crystal is much smaller than a glass the resonance frequencies are much, much higher."

Crystal Elastic Contents Revealed Two-component Superconductivity

Once underway, the team measured the response of the crystal's elastic contents, in which they exposed a variety of sound waves to the material as it was cooled to T_C. These elastic contents of the material revealed that Sr_2Ru0_4 is a two-component superconductor.

"A two-component superconductor is one in which the electrons can go into two possible ground states that have the same energy," noted Hicks. "Normally, there is only one ground state. In terms of bulk properties, it isn't a very important phenomenon: if you run a current through the material, you will see it superconduct.

"If you look closely, however, samples will have domains, because in some places it will choose one of the possible states and in other places the other. And you will then see lines between these domains where the superconductivity is suppressed, which is strange when you think about it: the electrons want to become superconducting, but can't because, right on these domain walls, they can't decide which state to enter."

These results ruled out Sr_2Ru0_4 being an s-, d-, or a p-wave superconductor. The team dubbed this material as a g-wave superconductor with an angular momentum of four.

Sr_2Ru0_4 May Combine Angular Momenta

"We have this material that superconducts, but we have no idea why," noted Hicks. "This particular material has too low a T_c to be commercially useful, it just annoys us physicists that we can't explain why it superconducts, and it is a material that a lot of people have happened to have looked at.

"It's a famous unsolved mystery, which attracts people. It could be a new form of superconductivity, and the understanding we gain might be applied to other materials, which is why it is worth solving this mystery."

The findings necessitate further research. The team intends to continue investigating the properties of Sr_2Ru0_4, as well as searching for a p-wave superconductor.

"[I just want to clarify that] it 'might' be a g-wave superconductor," cautioned Hicks. "Or, more strictly, d-wave with a g-wave component. You can combine even angular momenta – s, d, and g – because in all of these the spins point in opposite directions.

"Equivalently, one could combine p and f, but one can't combine s and p. Combining states like this means that if you took a snapshot and asked what the angular momentum of a particular pair of electrons was, sometimes the answer would be two, and other times four. And which answer you get is completely random.

"The next step is to figure out if this really is what the state is, and then to use that information to figure out why this compound is a superconductor in the first place. What interaction drives the Cooper pairing?"

Funding for this work was provided by the National Science Foundation Materials Research Science and Engineering Center (NSF MRSEC) program (DMR-1719875). ■

Currents

The Wind Energy Technologies Office of the U.S. Department of Energy has awarded $20.3 million to GE Research, the research division of General Electric Co., to accelerate the design and testing of a new superconducting wind generator.

With its past experience with both wind generators and MRI, GE believes that it can deliver more power without increasing the size and weight of the generator itself. Although the industries and applications are very different, the technical challenges have some similarities.

With MRI, the company has sought to increase the magnetic field of the superconducting magnets to deliver better image quality. With wind, researchers have attempted to strengthen the magnetic field of the magnet to make generators that deliver more power with higher efficiency. With both applications, minimizing size and weight is a key onjective.

Oxford Instruments NanoScience has announced two new customers in the UK for its Proteox dilution refrigerator. The first is Oxford Quantum Circuit (OQC), which will use the fridge for a superconducting quantum computer based upon its 3D Coaxmon qubits. OQC recently opened up its own quantum lab and plans to launch Quantum Computing as a Service in the future. OQC has established partnerships with Oxford Instruments NanoScience, Cambridge Quantum Computing, Riverlane, Rahko, and Oxford University as part of this effort.

The second customer is the University of Glasgow's Quantum Circuit Group. Glasgow is working on the design, manufacture, and test of superconducting quantum device funded by Innovate UK, the UK's innovation agency. The consortium also includes Glasgow's subsidiary and commercialisation partner, Kelvin Nanotechnology.

Proteox has been developed to provide a single, interchangeable modular solution to support multiple users and a variety of set-ups or experiments. It also includes remote management software which enables the system to be managed from anywhere in the world.

AMSC has entered into a delivery contract with the U.S. Navy for its HTS Ship Protection System (SPS) to be deployed on the San Antonio class of amphibious transport dock ship *USS Richard M. McCool Jr.* (LPD-29). This order represents AMSC's fourth ship protection system contract for the San Antonio class amphibious ship platform. The *USS Richard M. McCool Jr.*(LPD-29) will be the 13th amphibious transport dock ship of the USS San Antonio-class.

In AMSC's Q2 FY2020 quarterly earnings conference call, chairman, president and CEO Daniel P. McGahn , noted that the company was working with the Navy to understand the program timing for LPD 29 (see *Superconductor Week*, Vol 34, No 11). At that point, AMSC had three orders for deploying SPS on LPD 28, LPD 30 and LPD 31, and anticipated the potential for deployment on an additional 15 planned San Antonio-class ships.

The European Research Council (ERC) has awarded a consolidator grant to physicist Philippe Corboz of about €2.0 million euros. Consolidator grants are intended for researchers who obtained their PhDs 7-12 years ago to enable them to consolidate independent positions within their fields.

Corboz is an associate professor at the Institute for Theoretical Physics of the University of Amsterdam. His research is centered around the development and application computational methods for the simulation of strongly correlated quantum many-body systems, with a particular focus on 2D tensor network algorithms. A goal of his work is to develop the next generation of tensor network methods, and to use these methods to shed new light on challenging open problems, including high-temperature superconductivity, quantum spin liquids, and other novel states of matter.

Chinese quantum computing company Origin Quantum has secure over 100 million yuan ($15.4 million) in series A funding. The round was led by the China Internet Investment Fund with additional participation from the Guoxin Fund, CICC Qizhi, Chengdu Industrial Investment, CCB International, Zhongke Yucheng, Zhongtian Fortune, and Pangu Turing.

Origin Quantum, established in September 2017 and based in Heifei, China, is developing quantum computers based upon both superconducting and silicon dot technology. A six-qubit superconducting quantum processor was activated on the cloud and made available in September 2020 (see *Superconductor Week*, Vol 34, No 10). The company is working on a 24-qubit control system for superconducting quantum chips and computers, and has announced plans to launch a 60-qubit superconducting quantum computer by the end the year.

Due to COVID-19 related health concerns, the 15th European Conference on Applied Superconductivity, EUCAS 2021, will now be held in a virtual format beginning on Sunday, September 5, 2021. The duration of the conference will be announced after the virtual format is worked out.

The conference headquarters will remain in Moscow. EUCAS 2021 has issued a call for abstracts with a deadline of April 8. Further information is available at: https://www.eucas2021.org.

AMSC's senior vice president, CFO and treasurer John W. Kosiba sold 25,094 shares of the company on January 21 at an average price of $27.55 a share. The total sale was $691,340. In the twelve months preceding the sale, AMSC's share price rose 262.5%

UK industrial machinery manufacturer Avingtrans plc has announced that its two medical equipment businesses will merge with the Australian company Magnetica. Its UK subsidiary Scientific Magnetics designs and makes superconducting magnet systems, while its U.S. business Tecmag manufactures instrumentation.

Avingtrans currently holds an 82% majority interest in Scientific Magnetics and will become the majority shareholder in the combined business, with an initial interest of 58.4%.

The new entity will be known as Magnetica and will form part of Avingtrans' Medical and Industrial Imaging division. With the merger completed, Avingtrans hopes to become a leading MRI systems integrator for a variety of niche markets.

The U.S. Department of Energy has formally approved the scope, schedule and cost of the PIP-II project at DOE's Fermilab. The approval, known as Critical Decision 2 or CD-2, is an endorsement of Fermilab's detailed, formal plan for building the PIP-II accelerator, a high-power, superconducting machine that will become the heart of the laboratory accelerator complex.

PIP-II will send megawatt-scale proton beams, 60% higher than what Fermilab currently provides, to the lab's experiments. This high beam power is especially important for the international Deep Underground Neutrino Experiment, where scientists will seek to study neutrinos (see *Superconductor Week*, Vol 33, No 7). The particle accelerator project is the first in the U.S. that involves significant international contributions, with cavities and cryomodules being built in France, India, Italy, and the UK.

Materials scientist Amit Goyal, the director of the University of Buffalo's RENEW (Research and Education in eNergy, Environment and Water) Institute, was elected a fellow of the Institute of Electrical and Electronics Engineers (IEEE). The honor recognizes Goyal "for contributions to high-temperature superconducting materials." In addition to leading UB RENEW, an interdisciplinary institute dedicated to research and education on globally pressing problems in energy, environment and water, Goyal is a SUNY Distinguished Professor and SUNY Empire Innovation Professor in the Department of Chemical and Biological Engineering, and he has an adjunct appointment in the Department of Physics.

Goyal's research innovations have dealt with the fabrication of long lengths of high-performance, single-crystal-like, flexible superconducting wires at a price/performance metric equivalent to that of copper wires. His work also addressed the incorporation of an array of non-superconducting, columnar defects within the wires for enhanced performance in high-applied magnetic fields.

The designation is conferred by the IEEE Board of Directors upon scientists with an outstanding record of accomplishments in IEEE fields of interest. The total number selected in any one year cannot exceed one-tenth of 1% of the total voting membership. IEEE fellowship is the highest grade of membership and is recognized by the technical community as a prestigious honor and an important career achievement.

The Italian magazine *La Republica* named Anna Grassellino, a scientist at the U.S. Department of Energy's Fermi National Accelerator Laboratory (Fermilab), as Woman of the Year. Grassellino is the director of Fermilab's new Superconducting Quantum Materials and Systems Center (SQMS)(see separate article, this issue). She was selected from a list of 50 Italian women in different fields.

Grassellino is from Marsala, Italy, and studied electronic engineering at the University of Pisa. She received her doctorate from the University of Pennsylvania before joining Fermilab in 2012. Her specialty is superconducting radio-frequency (SRF) technology. She has received several awards for the discovery of nitrogen doping, a technique that dramatically increases the efficiency of SRF cavities. ■

Spotlight

Wolfgang Reiser is the Founder and Managing Director of Vision Electric Super Conductors.

Superconductor Week (SW): Why don't you start by telling us a bit about your personal background?

Wolfgang Reiser (WR): I am an electrical engineer and had my first years of learning, as I call them, at what is today ABB, in the industrial sector. I started working there with electrical equipment for industrial plants. Beginning at that time, I gained experience with the many different technologies you need for industrial plants, from high voltages down to small amperages, to high-amperage, high-power switch gears, transformers, motors, cables, control units … everything. In addition, I got a chance to participate in different project phases. I started with the erection, installation, and commissioning of programmable controllers in an industrial plant. I also did some acquisitions, quotation work, some negotiations with customers, and order processing, so I experienced all those different phases of project development.

SW: Was this at the ABB branch in Kaiserslautern?

WR: No, not in Kaiserslautern, but in Mannheim, which is the biggest branch worldwide of ABB. In those days it was Brown Boveri; this was before the merger of Brown Boveri with ASEA in the second half of the 80's.

SW: Which entity was the Swiss one?

WR: Brown Boveri was originally founded in Switzerland, in Baden. And ASEA was in Västerås, Sweden. The largest subsidiary was in Mannheim, because when the city started to build up its grid, they required a local company to be involved. In my days, Brown-Boveri in Mannheim managed about 35,000 people in Germany. And in Switzerland we had about 20,000 people. So Mannheim was much larger than Switzerland.

SW: I assumed that back then the grid in Mannheim was state-owned, or government owned, because they can then mandate that…

WR: Yes, it was the city. In those days everything was city-owned or regional-owned.

SW: A public good.

WR: As it is today again.

SW: Well, it makes sense for a lot of reasons.

WR: After six years at Brown Boveri I changed over to Erico, a small international company with its headquarters in Cleveland, Ohio.

SW: I see.

WR: But they had a German office and I moved there as a technical manager. After a few years I became general manager; then, again after a few years, I joined the board of directors of Erico Europe. I then founded my own company, called Vision Electric, as a startup, and parallel to that I got the opportunity to buyout the production of Erico in Germany. So, in 2000, I managed two companies at the same time, the startup and a takeover. Both were not profitable in the first year; it was a "black zero" as we say.

SW: Better than losses, I suppose.

WR: Yes, we had no losses but also no profit. But we had a turnover of €3.0 million and, in the following years, we expanded our business dramatically; we worked on a worldwide basis. In 2012 we sold all our businesses. We had, in the meantime, founded several companies, small entities, because we were convinced that we could better control smaller units and could better respond to our markets. So we sold everything in 2012 when we had a total turnover of €55.0 million. That was a factor of 18 within 12 years.

SW: Kudos, good for you. Just to distinguish between Vision Electric and Vision Electric Super Conductors, which we will discuss shortly, was the former also a manufacturing company or were you just an engineering company focused on grid solutions and general electrical engineering services?

WR: Vision Electric was an engineering office specializing in high current applications with specialized high quality production of busbars. This was a nice concept because we had developed a lot of know-how in the high current field, but we did not sell our know-how as engineers, we sold products, which was much more interesting.

SW: Why?

WR: Margin.

SW: Sure. That's how you got the €55.0 million turnover.

WR: Yes. We sold material. Can you imagine, from Kaiserslautern we were shipping about 1000 tons of materials in 2004 to Rajasthan in India for a zinc plant. Everybody said that India has low labor costs, they have all the materials and so on, but we had the engineering. We sold our material from here to India because we were better at the engineering.

SW: I'm not surprised by that.

WR: That was fun. I personally travelled throughout the world. I think I visited India about 15 or 20 times. We sold to Russia, to China, to North America. As Vision Electric, we were certified by the U.S. Department of Energy for nuclear purposes, and we supplied a busbar system for a nuclear waste disposal project in the state of Washington.

SW: Very cool.

WR: That was one of the projects. We made busbars in Dubai for an aluminum plant. I was the first to introduce copper flexibles to an aluminum plant; aluminum plants normally do not accept copper, but at a New Zealand aluminum smelter they wanted to have an upgrade and had no space. Copper carries more current than aluminum on the same cross-section, so I did all these funny and special things. I believe there were not 30 companies in the world that could do the same as we did, maybe not even ten of them.

SW: Help me understand the transition from divestment in Vision Electric to the founding of Vision Electric Super Conductors.

WR: Okay. One reason we sold is because my partner was 67 years old and wanted to retire and get out of the business. I didn't want to start anew or continue with another partner, so we said we'd both sell together. I was relatively young and had two visions. One was to build a new house, which I did. The second was to start up once more a new company in the same field, dealing with the same markets, the high-current industry, but with superconductors. I believe that superconductors are on the edge of moving from laboratory to industry, and we are working currently on that.

So, in 2014, I started Vision Electric Super Conductors with several other people. Now, in 2021, we are more than seven years old. We have invested a lot of time in developing superconducting busbar systems or superconducting cables, and we see there is much more that can be done; not only high-current industry applications but in others as well. We built our first demonstration at BASF in Ludwigshafen; that was only possible because I had been working with BASF for the past 30 years. People knew me; when I told my contact what I wanted to do over the course of two hours, he said, yes, we will do it. Then he got all the approvals from the senior hierarchy.

SW: That's not easy at a company like BASF.

WR: No, absolutely not. There are so many regulations. They conduct so many risk-assessments; they have so much concern about environment,

‣ safety, and health. And the greatest difficulty was that we wanted to install something in a production plant in operation. So the first goal was not to disturb the production at all.

SW: Of course, in any manufacturing company the production comes before everything else. You can't stop or you have to pay fines. If a supplier stops production they have to pay for it or something, at least in some industries.

WR: No, we didn't pay for anything. It was in their chlorine plant, and chlorine is in three quarters of their production processes, so if the chlorine plant failed, that would have been a disaster for three quarters of the whole production in Ludwigshafen, and Ludwigshafen is the largest chemical conglomerate worldwide.

SW: Yeah. Huge.

WR: That was the additional difficulty, which we had to master. Why we did we want to do this in an operating plant? Because we wanted to prove that the system was ready to install in industry, and in an operating plant it is more difficult than in a greenfield plant, when you are not already in operation and are just starting up. This made it more difficult but we mastered all the different elements; we conducted tests, we carried out risk assessments. We sometimes had about 10-15 BASF people in one row at the table while we were 4-5 people on the other side.

SW: So, how were you able to pitch this successfully to them? Was the goal space reduction or just improving power distribution and efficiency?

WR: I just told them we need a place where we can demonstrate that our system was ready for industrial use. Of course they did not pay for that demonstration. We got money from the state, although the project was mainly financed by the shareholders of the company.

SW: How much of your intellectual property is related to research at the Karlsruhe Institute of Technology (KIT)? Is that a partnership that came about before or after this project?

WR: We are working closely together with KIT, and we've received a lot of knowledge about superconductors from them. We were introduced into scientific circles by KIT. This was quite a benefit, getting in contact with other institutes and people that were working on superconductors.

SW: Correct me if I'm wrong, but isn't that also a path to the appropriate people in government that award grants?

WR: No, that is different. The grants in KIT are coming from different places than the grants for industry.

SW: I noticed on your website that you are also receiving some support from the state of Hamburg.

WR: Yes, that was a support letter. Up until now we have not received any financial support but we hope to get that in the future.

SW: The intention is there.

WR: Yes. That was the first step; the next step is to ask them for money.

SW: Not as easy, I'm sure.

WR: No. Everybody is keeping their money in their pockets. The nice thing is that we are not in the superconducting field, we are very strongly related to applications. That is our advantage; we know what the customer needs and what he is looking for, and we know how to translate superconductivity technology into an application technology.

SW: Right, that's what is unique about your company. What distinguishes your showcase ICEBAR superconducting busbar product is its modularity, and the fact that it can be used in so many different applications.

WR: That is one of the features, and that is coming through our past experiences. We found that it is good to have modules that can connect just like Lego pieces.

SW: It's also easier for production.

WR: You can easily upscale, you can increase and adapt your production according to the quantities you need. From a production and installation point of view, yes, modules help a lot and make life a lot easier because you have a repetition in the production; you have a scale-up factor, and things like that.

SW: Yeah, that makes perfect sense.

WR: But, most importantly, we are coming from the application side. And the people I am working with here, most of them are coming from Vision Electric, so they have the experience. They have been working with me for almost 20 years or sometimes longer, and that's a big advantage. So we have taken the know-how from superconductors, we have put that together with the know-how of our industry, which we know, and we have brought both together into a project.

SW: So, two things I'm going to ask. One is to give me the 'flyer introduction' of your product, and then go through several applications. I want to hear you talk about data centers, power transmission, aluminum smelting, or other smelting. I'll come back to this question later, but what level of commercialization have you already achieved, how much of this is still purely R&D, how many of these units are you shipping out, etc.

WR: Great; let's discuss first where we stand at the moment. We have successfully demonstrated that the 20 kA at BASF is industry safe. We are working on a 200 kA system, which is a factor of 10 above the BASF system. With this we hope that we can then win our first real economic project. Until now, we have not done any real commercial projects, so we are looking for the first one. We are, therefore, working in different application sectors. We are working in industry, which means the large current industry, starting with chlorine. These days hydrogen is something that is also interesting. Zinc, copper, aluminum … these are all electrolytic processes requiring very high currents. Today currents up to 500 kA are undergoing tests in aluminum industries for production. 500 kA is greater than any natural current, even the strongest lightning strike.

SW: Crazy.

WR: Absolutely. That is one of the fields that was part of our old business, and where we have contacts, so it's a question of time when we get our first order. The second area is data centers. Here we are looking to the huge data centers, those that are run by Google, Amazon, Facebook … The big data centers that require power of a hundred megawatts and more.

SW: Alibaba, Tencent.

WR: Maybe Alibaba, but I have my difficulties working in China.

SW: I know, but they have huge data centers. There is a government initiative to put a bunch of data and cloud server centers in the western interior of China, in Guizhou province, so there are tons of these new data centers popping up. Anyway, it would be an opportunity, but yeah, a complicated market.

WR: Not so complicated, but in data centers, since about 15 years ago, there have been a lot of papers suggesting that changing over the power structure from AC to DC would save between 15% and 25% of the power losses, and data centers eat a lot of power. In California, the last that I read was that they used between 2.5% and 3.0% of the total production of power in the whole state. We are hearing about data center power consumption because the Frankfurt region is going through a large boom for building up data centers. They are popping up because of Brexit; the Londoners are coming over to Frankfurt.

SW: That makes sense; all the big banks would require data centers.

WR: At the moment, in the Frankfurt region, 20% of total power consumption goes to data centers.

SW: Wow, that's crazy.

WR: Yeah. And of course, they want to be more sustainable. They want to use more renewable energy and integrate solar and wind power, and have enough battery capacity, which are all on DC. But if large data centers are using aluminum or copper, they are losing a lot on the copper because of resistance and power losses. Therefore, superconductors are ideal because they have no losses; they will increase savings from 15-25% to about 20-30% for large power data centers. So that is also one of the markets we are looking at, but of course it is difficult gain entry. We are working here with ABB.

We also determined that DC is very attractive also for grids, which is a completely new market for us as well. We got into contact with some political organizations, and received support letters from Hamburg and from Kiel, Schleswig-Holstein. The problem is that HVDC power lines; you know what HVDC is?

SW: High voltage direct current line.

WR: Yes. If you are using cables in Germany you are not allowed to build overhead HVDC lines anymore, so if you are going to …

SW: There are no overhead lines in Germany?

WR: No new ones.

SW: Why?

WR: Our population is at a much higher density than in the United States, and if you are traveling here, around every two, three or four kilometers you come across a village, and no one wants to live in the vicinity of overhead lines.

SW: They are ugly, I understand.

WR: That's in all of Germany. In the meantime there is an additional law that says wherever possible, cables should be used, and of course, cables are possible.

SW: That's a good thing for you, and for anybody else involved in this business.

WR: Yes. And if you go to cables and HVDC systems, then the maximum power at the moment, and that is at least for the next 10-15 years, is 2 GW. Now, we are going to change our energy grid in the coming years and will have to carry more wind power from the north to the south. In the coming years, we are switching off all of our nuclear plants and most of them are located in the south, because the industry is there. We will have to take power from the North Sea to the south of Germany, which is roughly about 1000 km.

SW: That means, how do you transport all this power from out in the North Sea to southern Germany?

WR: Yes, and the thing is, superconductors can do the same job that HVDC does on medium voltage. The first advantage is that medium voltage is much easier to handle, to deal with, and, secondly, because superconductors have no resistance, you have no losses. At the moment, on the HVDC SüdLink, we are installing a HVDC of 4 GW, that is two times 2 GW, over 700 km. If you feed in 4 GW on one side, you get out 3.7 GW on the other side, which means you have a loss of 300 MW. And if you installed 300 MW offshore, you have about half a billion or three quarters of a billion as just the investment cost for the wind towers.

SW: Wow.

WR: Superconductors can do that job and do it better, because with superconductors if you feed in 4 GW you get out 4 GW. But if you are doing that on medium voltage, you don't have 500 kV, which is in the HVDC, but only 50 kV, which is medium voltage and can be handled easily. And if you have just 20 kA, which will have already demonstrated, then you are already there with 2 GW. So, if you are going to 50 kA, which is a superconductor just that size, not more, then you are coming to a power of 5 GW. The European Union has defined common points of interest and they are planning to install a network of platforms or artificial islands in the North Sea to collect all the wind from the wind farms and distribute them to different countries when they need it. The maximum power of one of these energy islands, or energy platforms, is about 10 GW. So we need something to connect in the range 5 or 10 GW and that is only possible at the moment with superconductors, just from the concept.

Of course, the two true renewable energies that are available on demand are bio and water. Norway, Switzerland, and Austria have a lot of water.

SW: Well, with glaciers, they have the geographic luxury.

WR: Hydro is enormous there. So, Germany will be the transfer point for all of Europe.

SW: Germany is the consumer.

WR: Yeah, we are the consumer, but we will also export and import, and transfer through Germany, from Norway maybe to Austria or to Switzerland. So, water power from Norway against wind power and solar from the south; that is the mix.

SW: How are they tackling storage? Where are they

▸ going to store latent energy?

WR: Of course you will need some storage; that is the next big step for Europe, storage by hydrogen. That is the hype at the moment. And for hydrogen, of course, you also need renewables. You will need abundant renewables so that you have enough current to transfer into hydrogen if the efficiency is not very good.

So we are now ready to demonstrate a system in superconducting MVDC and at the moment we are preparing a feasibility study comparing HVDC to MVDC. I've already gotten feedback from some companies that are already going to install platforms in the North Sea; they said that most of the cost of the platforms is coming from the size of those huge HVDC converter stations. You can imagine, it's at the power of three that is between medium and high voltage, so if you can reduce the voltage you are saving a lot of the cost for those platforms. That is the interesting feature for those companies.

SW: There's so much savings, also just material savings.

WR: Everything. So I think we have a huge potential lane in front of us. But, on the other hand, we are drilling a large hole in a thick board.

SW: Well, so is everybody else involved in superconductivity. You know, I've talked to a lot of people who have been doing this since Bednorz and Müller made their discovery of HTS in 1987; they've been working on this since 1987 and it is still not 100% commercialized, so it's taking …

WR: Yes, but in recent years, the production of HTS has been moving from laboratories to industry. I remember very well visiting SuperPower in Schenectady, New York. They showed me their production line. It was a large laboratory, nothing else; it was not industrial.

And, today, if you are looking at the production of SuperOx or THEVA, that's industrialized production. You've got better performance on your tapes, and you've got longer lengths. And it continues, year by year, either performance is going up or price is going down. That is what drives us, but price is not related to time. The price decrease is related to the quantity that is produced. I believe if there are the first two, three or four initial projects, then the demand will increase.

SW: What is Vision Electric Super Conductors running on? Do you have private investors or are you running on cash reserves of your own? How does the company make income to continue its R&D?

WR: We are not profitable at the moment and are still financed by our shareholders in different ways. And also I have a lot of private money in the company.

SW: Right, you founded the company; this is your passion and interest.

WR: Definitely.

SW: So, when do you project that you will be able to scale up to commercial production? After your demonstration of a 200 kA busbar…

WR: The difficulty in predicting at the moment is the general hesitation of investors to spend, or industries to spend some money because of the slowing down of the whole economy. The coronavirus is one of the biggest factors at the moment. For example, last year in January, we appointed our first sales representative and consultant in Indonesia, which is an emerging market. They need a lot of energy; they need to upgrade their grid and do things like that. There are definitely projects available in Indonesia, but all of them are on hold at the moment.

SW: Superconductivity has the potential to be a great equalizer, I think, for a lot of societies that are disadvantaged by their infrastructure. Obviously, things are fine in Europe and the U.S. where we have very robust infrastructure systems, but if you could make superconducting cable grids, and do it like a copy-paste thing, imagine the benefits to underdeveloped economies…

WR: I have activated my sales representative in India and this morning I had an online meeting with Australia, which is not underdeveloped but they have big plans.

SW: They have huge distances to span, there are

‣ other challenges in Australia.

WR: Yeah, and they are talking about connecting to Indonesia and Singapore for the supply of their large production of solar energy.

SW: Wow.

WR: These might be only ideas for now, but maybe these ideas come into reality someday.

SW: I think that if there are 100 big ideas and you can successfully hit three of them, you are good.

WR: I think we have to follow all of them, and see which ones are good. But coming back to your question, I think that we might reach our first real commercial order by the end of this year or maybe next year. That is my expectation. And a real commercial order is something in the range of between €5.0 million and €15.0 million. That is what I would call a medium size order. But the potential is there for multimillion-euro orders.

SW: Certainly, and there's so much government incentive now for these types of technologies as well, because of climate, etc.

WR: And not only in Europe or Germany, but also worldwide.

SW: So, as someone who has been working in superconductivity for a long period of time, what advice do you give to younger people who want to get involved in the industry, or to graduate students who are working on superconductivity? What would you say to them?

WR: Good question, but first of all, you have to do what you like and what you are enthusiastic about. That is general advice. On superconductivity: yes, there are a lot of new technologies around, but superconductivity is a technology that is, as I would say in German, it is a Querschnittstechnologie. It is connecting a lot of different fields; it is a cross-sectional technology. It can be used in many different applications, and therefore it is a future industry in almost every technological field that we know today. Even if you look quantum computing, or artificial intelligence, they are operating at low temperatures, so superconductivity is one of the enablers at cryogenic temperatures.

SW: Right, for the medical industry they still have to use low temperature superconductors for all these MRI machines, etc.

WR: Right, so at every turn in the future you will find a superconductor. Superconductors will be more common, and the good thing is that we have to make them in just the same way as a normal cable.

SW: The last guy I interviewed said they are going to be like flush toilets.

WR: That is a good comparison; it could be something usable by everybody.

SW: Thank you for your time. ■

Luminary

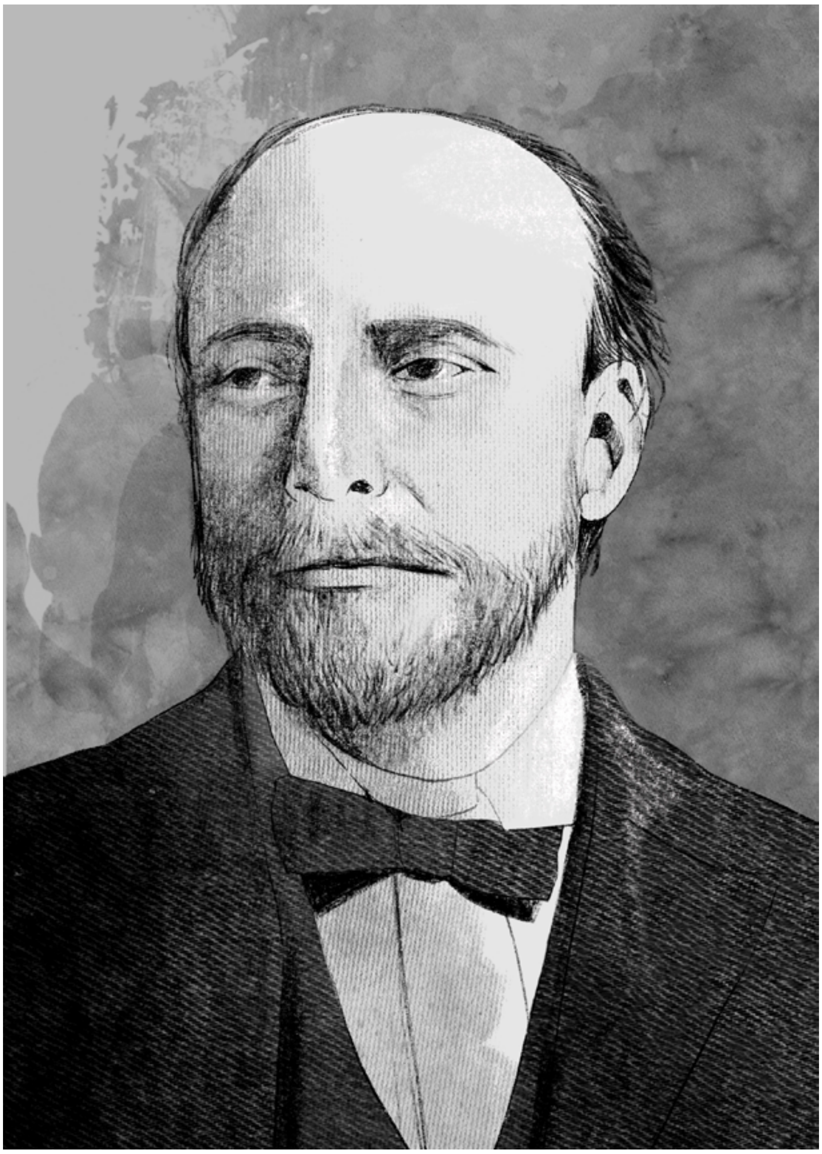
Born to a vintner and innkeeper in Kindcardine, Perthshire, James Dewar was the youngest of six brothers. He attended local schools until the age of 10, when he contracted rheumatic fever. He spent the following two years convalescing, during which time he took up violin making, which he would later credit for his dexterity in the lab.

Dewar's parents died when James was only 15. Shortly afterwards, in 1858, he attended the University of Edinburgh where he studied under Lyon Playfair. In 1867, he invented a mechanical device to represent graphic notation for organic compounds, which impressed his colleagues and led to an invitation to study under August Kekulé in Ghent.

In 1869, Dewar became a lecturer on chemistry at the Royal Veterinary College of Edinburgh. Since working with Kekulé, he had developed an interest in benzene, and the following year produced the pyridine ring formula, substituting a nitrogen atom for a CH residue in the ring.

In 1871, Dewar married Helen Rose Banks, the daughter of a wealthy Edinburgh printer. They had no children and remained together until his death.

Dewar was elected Jacksonian Professor of Natural Experimental Philosophy at the University of Cambridge and became a member of the Royal Institution, where he later became Fullerian Professor of Chemistry. He joined with George Downing Lieving, a Cambridge colleague, to correlate line and band spectra with atomic and molecular states. The two would publish 78 papers together on the topic between 1877 and 1904.



James Dewar 1842-1923

Around the same time Dewar began his investigations into the electrical behavior of substances at ultra-low temperatures, which would become one of his primary fields of study. He developed this interest shortly after Louis Cailletet and Raoul Pictet successfully liquefied small amounts of oxygen and nitrogen. Dewar would replicate this feat in 1880 in a public demonstration.

In 1891 Dewar designed and built machinery that yielded liquid oxygen in industrial quantities. The machine was able to draw liquefied gas through a valve to be used as a coolant. He showed that both liquid oxygen and liquid ozone are both strongly attracted by a magnet.

The following year Dewar invented the Dewar flask, a vacuum-jacketed vessel for the storage of liquid gases, which would become his most famous contribution to the sciences. The flask was extremely efficient at preventing heat transfer; it consisted of two flasks, one inside the other and separated by a vacuum.

Though Dewar is credited for inventing the flask, he failed to make any money off of it. His design was hijacked by Thermos, a German company, which used it to manufacture commercial containers to keep beverages at their desired temperature. Dewar took Thermos to court, but failed to retain the intellectual property rights.

With his flask, Dewar was able to preserve liquids for longer periods and to examine their optical properties. He successfully collected liquefied hydrogen in 1989 and solidified hydrogen in 1899, which left helium as the only gas yet to be liquefied and solidified. Dewar spent a decade trying to liquefy helium without success. Unfortunately, he obtained helium from the bubbling springs of Bath, but these samples also contained neon, which solidified in the cooling process and blocked the valves of his apparatus.

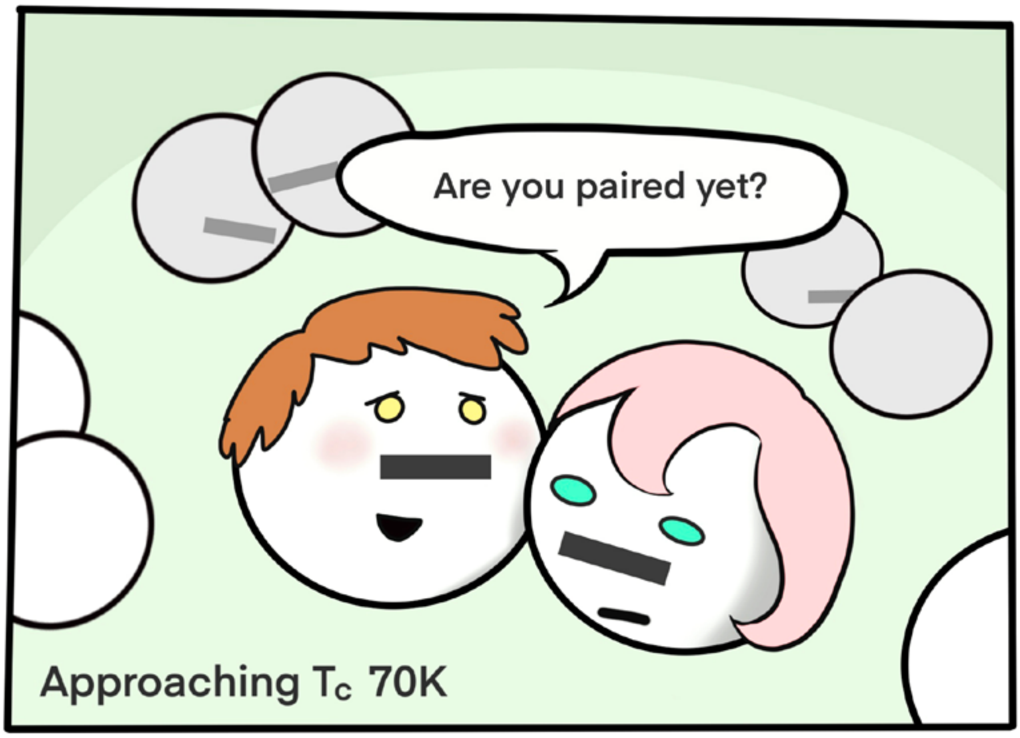
Using many of Dewar's methods, Heike Kamerlingh Onnes produced liquid helium in 1908, isolating the element from monazite, and promptly won a Nobel Prize for his discovery, a laurel that evaded Dewar throughout his life despite numerous nominations.

The outbreak of World War One made Dewar's expensive cryogenic research impossible. After the war, he showed little interest in resuming this work and spent much of his remaining years investigating the surface tension of soap bubbles, a topic that had fascinated him since the 1870s.

Dewar had a reputation for being fiercely individualistic and irascible, preferring to work alone. He was an indifferent teacher yet an inspiring public lecturer. His interests were so vast that his texts touch on a fraction of his scientific contributions, which spanned the gamut of physical science. His cryogenics research contributed to later experimentation with superconducting materials.

In 1923 he passed away while engaged in measuring infrared radiation from the sky. In his long and prolific career, Dewar was a steadfast experimentalist and never once published a theoretical paper. A lunar crater bears his name. ■

Superconducting Humor



Patents

Vertical flux bias lines coupled to vertical squid loops in superconducting qubits
Intel Corp.
December 29, 2020
U.S. Patent No. 10,879,446
Embodiments of the present disclosure relate to quantum circuit assemblies implementing superconducting qubits, e.g., transmons, in which SQUID loops and portions of flux bias lines (FBLs) configured to magnetically couple to the SQUID loops extend substantially vertically. In contrast to conventional implementations, for a vertical SQUID according to various embodiments of the present disclosure, a line that is perpendicular to the SQUID loop is parallel to the qubit substrate. A corresponding FBL is also provided in a vertical arrangement, in order to achieve efficient magnetic coupling to the vertical SQUID loop, by ensuring that at least a portion of the FBL designed to conduct current responsible for generating magnetic field for tuning qubit frequency is substantially perpendicular to the substrate.

Repeating alternating multilayer buffer layer
Northrop Grumman Systems Corp.
December 29, 2020
U.S. Patent No. 10,879,447
A buffer layer can be used to smooth the surface roughness of a galvanic contact layer (e.g., of niobium) in an electronic device, the buffer layer being made of a stack of at least four (e.g., six) layers of a face-centered cubic (FCC) crystal structure material, such as copper, the at least four FCC material layers alternating with at least three layers of a body-centered cubic (BCC) crystal structure material, such as niobium, wherein each of the FCC material layers and BCC material layers is between about five and about ten angstroms thick. The buffer layer can provide the smoothing while still maintaining desirable transport properties of a device in which the buffer layer is used, such as a magnetic Josephson junction, and magnetics of an overlying magnetic layer in the device, thereby permitting for improved magnetic Josephson junctions and thus improved superconducting memory arrays and other devices.

Semiconductor and ferromagnetic insulator heterostructure
Microsoft Technology Licensing, LLC
December 29, 2020
U.S. Patent No. 10,879,464
A first aspect provides a topological quantum computing device comprising a network of semiconductor-superconductor nanowires, each nanowire comprising a length of semiconductor formed over a substrate and a coating of superconductor formed over at least part of the semiconductor; wherein at least some of the nanowires further comprise a coating of ferromagnetic insulator disposed over at least part of the semiconductor. A second aspect provides a method of fabricating a quantum or spintronic device comprising a heterostructure of semiconductor and ferromagnetic insulator by forming a portion of the semiconductor over a substrate in a first vacuum chamber, and growing a coating of the ferromagnetic insulator on the semiconductor by epitaxy in a second vacuum chamber connected to the first chamber by a vacuum tunnel, wherein the semiconductor comprises InAs and the ferromagnetic insulator comprises EuS.

Superconducting field-programmable gate array
PSIQuantum Corp.
December 29, 2020
U.S. Patent No. 10,879,905
The various embodiments described herein include methods, devices, and systems for operating superconducting circuitry. In one aspect, a programmable circuit includes: a superconducting component arranged in a multi-dimensional array of alternating narrow and wide portions; a plurality of heat sources, each heat source thermally coupled to, and electrically isolated from, a respective narrow portion of the multi-dimensional array; and a plurality of electrical terminals, each electrical terminal coupled to a respective wide portion of the multi-dimensional array.

Superconducting wire
Sumitomo Electric Industries, Ltd.
January 5, 2021
U.S. Patent No. 10,886,040
A superconducting wire includes a stack which includes: a first substrate having a first primary surface; a second substrate disposed opposite the first substrate; and a first superconducting material layer between the first primary surface and the

second substrate. A ratio of a width of the superconducting wire to a height of the superconducting wire in a cross section perpendicular to the longitudinal direction of the superconducting wire is 0.8 or greater and 10 or less. The width is 2 mm or less.

Coiled coupled-line hybrid coupler
Northrop Grumman Systems Corp.
January 5, 2021
U.S. Patent No. 10,886,049
A superconducting on-chip coiled coupled-line 90° hybrid coupler is made of a series array of repeated cells of coiled transmission lines that are inductively and capacitively coupled. The coupler splits an incoming microwave signal into two output signals of roughly equal power and separated in phase from each other by roughly 90°. The coupler can be incorporated into such superconducting electronic circuits as clock-distribution networks for reciprocal quantum logic (RQL) systems, as well as Josephson-based phase shifters and vector modulators.

Superconducting circuit and method for detecting a rising edge of an input signal
Microsoft Technology Licensing, LLC
January 5, 2021
U.S. Patent No. 10,886,902
Superconducting circuits and methods for detecting a rising edge of an input signal are described. An example superconducting circuit includes an input terminal for receiving an input signal comprising both positive pulses and negative pulses. The superconducting circuit further includes a first stage, coupled to the input terminal and a first node, configured to suppress both any backward propagating negative pulses and any forward propagating negative pulses, and allow propagation of any forward propagating positive pulses. The superconducting circuit further includes a second stage, coupled to the first node, configured to store a forward propagating positive pulse and reflect a stored positive pulse back to the first node as a negative pulse such that in response to each rising edge of the input signal a return-to-zero signal comprising both a rising edge and a falling edge is provided as an output at the first node.

Self-monitoring superconducting tape via integrated optical fibers
North Carolina State University
January 12, 2021
U.S. Patent No. 10,892,397
Disclosed are systems and methods for a self-monitoring conducting system that can respond to temperature, strain, and/or radiation changes via the use of optical fibers. The self-monitoring conducting system comprises a conducting component integrated with one or more optical fibers. The temperature, strain, and/or radiation changes can be sensed or detected via optical interrogation of the one or more optical fibers.

Quench protected structured superconducting cable
The Texas A&M University System
January 19, 2021
U.S. Patent No. 10,896,773
Quench protected structured (QPS) superconducting cables, methods of fabricating the same, and methods of bending the same are disclosed. The methods of bending the QPS superconducting cables can be employed to produce windings. The QPS superconducting cables can rapidly drive a distributed quench to a normal conducting state in a superconducting cable if a region of the cable spontaneously quenches during high current operation.

Ion beam mill etch depth monitoring with nanometer-scale resolution
The Regents of the University of California
January 19, 2021
U.S. Patent No. 10,896,803
A method for measuring conductance of a material real-time during etching/milling includes providing a fixture having a socket for receiving the material. The socket is attached to a printed circuit board (PCB) mounted on one side of a plate that has at least one opening for providing ion beam access to the material sample. Conductive probes extend from the other side of the PCB to contact and span a target area of the material. A measurement circuit in electrical communication with the probes measures the voltage produced when a current is applied across the material sample to measure changes in electrical properties of the sample over time. The invention enables the fabrication of thin films needed to produce high-quality HTS Josephson junctions using a sub-nanometer focused beam of ions to direct-write insulating barriers into HTS films

Systems and devices for filtering electrical signals
D-Wave Systems, Inc.
January 19, 2021
U.S. Patent No. 10,897,068
Adaptions and improvements to coaxial metal powder filters include distributing a dissipative matrix mixture comprising superconductive material, metal powder, epoxy, and/or magnetic material within a volume defined by an outer tubular conductor and inner conductor. The frequency response of the filter may be tuned by exploiting the energy gap frequency of superconductive material in the dissipative matrix. The inner surface of the outer tubular conductor may be covered with a superconductive material. For a dissipative matrix comprising magnetic material or superconductive powder particles of a certain size, an external magnetic field can be applied to tune the frequency response of the filter.

Quench protection device of superconducting magnet system and working method thereof
Hefei CAS Ion Medical and Technical Devices Co., Ltd.
January 19, 2021
U.S. Patent No. 10,897,129
Disclosed is a quench protection device of a superconducting magnet system, including a superconducting coil set; the superconducting coil set comprises two superconducting coils which are symmetrical arranged, and each of the two coils is connected in parallel with a protection diode; the superconducting coils and the protection diode are connected with the power supply via a conductive wire; the superconducting coils set are connected in parallel with a quench protection unit, a change-over switch is arranged on a circuit of the two coils, the protection diode, and the power supply, and the change-over switch is connected with an external resistor via a conductive wire. The change-over switch of the quench protection device connects the superconducting coil and an external resistance, which realizes the quench protection of the coil.

Superconducting signal amplifier
PsiQuantum Corp.
January 19, 2021
U.S. Patent No. 10,897,235
A system includes a first superconducting wire and a second superconducting wire connected in parallel. The system includes a first current source coupled to the first superconducting wire and configured to supply a first current in response to a trigger event. The system includes a second current source coupled in series with the parallel combination of the first and second superconducting wire and configured to supply a second current. The superconducting wires are configured to, while receiving the second current, operate in a superconducting state in the absence of the first current. The first superconducting wire is configured to, while receiving the second current, transition to a non-superconducting state in response to the first current. The second superconducting wire is configured to, while receiving the second current, transition to a non-superconducting state in response to the first superconducting wire transitioning to the non-superconducting state.

Linear media handling system and devices produced using the same
Infinity Physics LLC
January 26, 2021
U.S. Patent No. 10,899,575
An improved system for handling delicate linear media and in particular to a method and apparatus for winding delicate linear media such as superconducting wire or tape or optical fibers onto a spool. A combination of direct closed loop control and media routing design facilitates the handling of the delicate media without causing damage. The axial tension in the linear media may be closely controlled during winding by means of feedback control loop using tension measurements to control the rotation speeds of the wind-from and wind-to spools. Further, during winding, the delicate linear media is only exposed to large radius bends with no reverse bending. Finally, output devices and features, commercial or otherwise, made possible by delicate linear media handling are revealed. This includes advanced superconducting devices and features.

Diffusion barriers for metallic superconducting wires
H.C. Starck, Inc.
January 26, 2021
U.S. Patent No. 10,902,978
In various embodiments, superconducting wires incorporate diffusion barriers composed of Nb alloys or NbTa alloys that resist internal diffusion and provide superior mechanical strength to the wires.

Semiconductor Josephson junction and a transmon qubit related thereto
University of Copenhagen
January 26, 2021
U.S. Patent No. 10,903,411
The present disclosure relates to semiconductor based Josephson junctions and their applications within the field of quantum computing, in particular a tuneable Josephson junction device has been used to construct a gateable transmon qubit. One embodiment relates to a Josephson junction comprising an elongated hybrid nanostructure of superconductor and semiconductor materials and a weak link, wherein the weak link is formed by a semiconductor segment of the elongated hybrid nanostructure wherein the superconductor material has been removed to provide a semiconductor weak link.

Qubit frequency tuning structures and fabrication methods for flip chip quantum computing devices
IBM Corp.
January 26, 2021
U.S. Patent No. 10,903,421
A quantum computing device includes a first chip having a first substrate and one or more qubits disposed on the first substrate. Each of the one or more qubits has an associated resonance frequency. The device further includes a second chip having a second substrate and at least one conductive surface disposed on the second substrate opposite the one or more qubits. The at least one conductive surface has at least one dimension configured to adjust the resonance frequency associated with at least one of the one or more qubits to a determined frequency adjustment value.

Amplifier frequency matching for qubit readout
Google LLC
January 26, 2021
U.S. Patent No. 10,903,809
A quantum computing devices includes: a qubit; a readout device coupled to the qubit, the readout device including a frequency filter having a filter frequency range; and an amplifier device coupled to the readout device, in which the amplifier device is configured to amplify a measurement signal from the readout device upon receiving a pump signal having a pump frequency that is outside of the filter frequency range of the frequency filter.

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