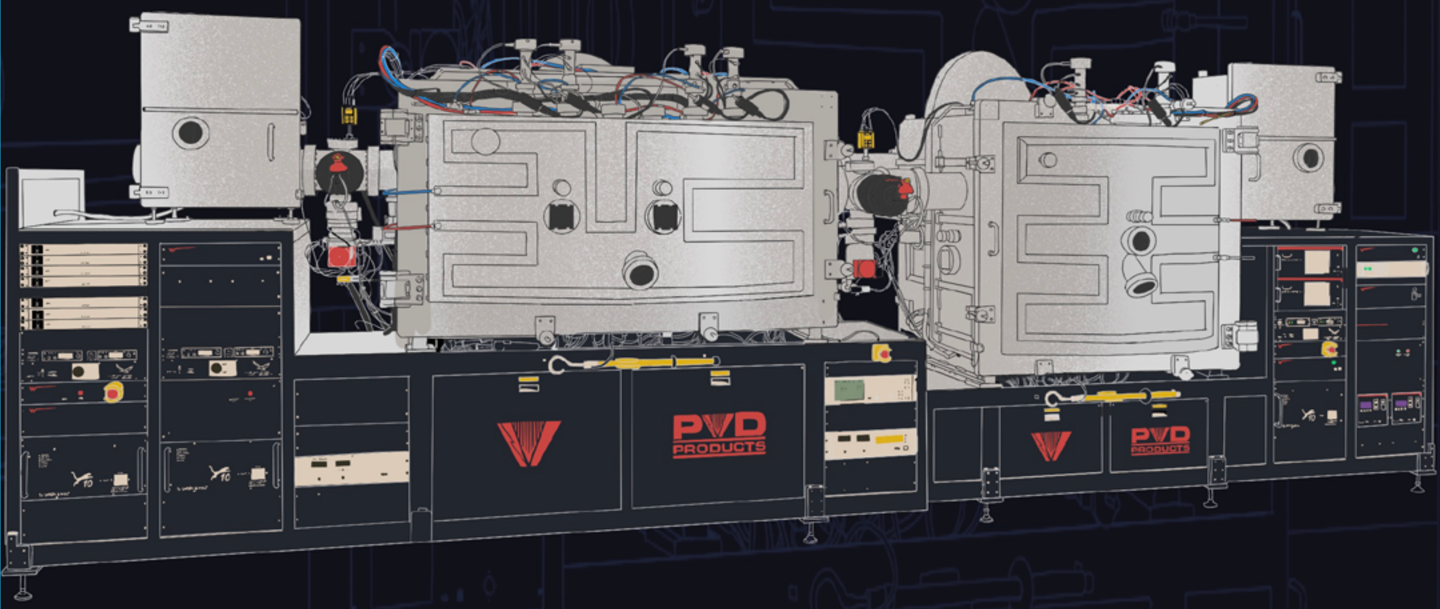
SUPERCONDUCTOR WEEK



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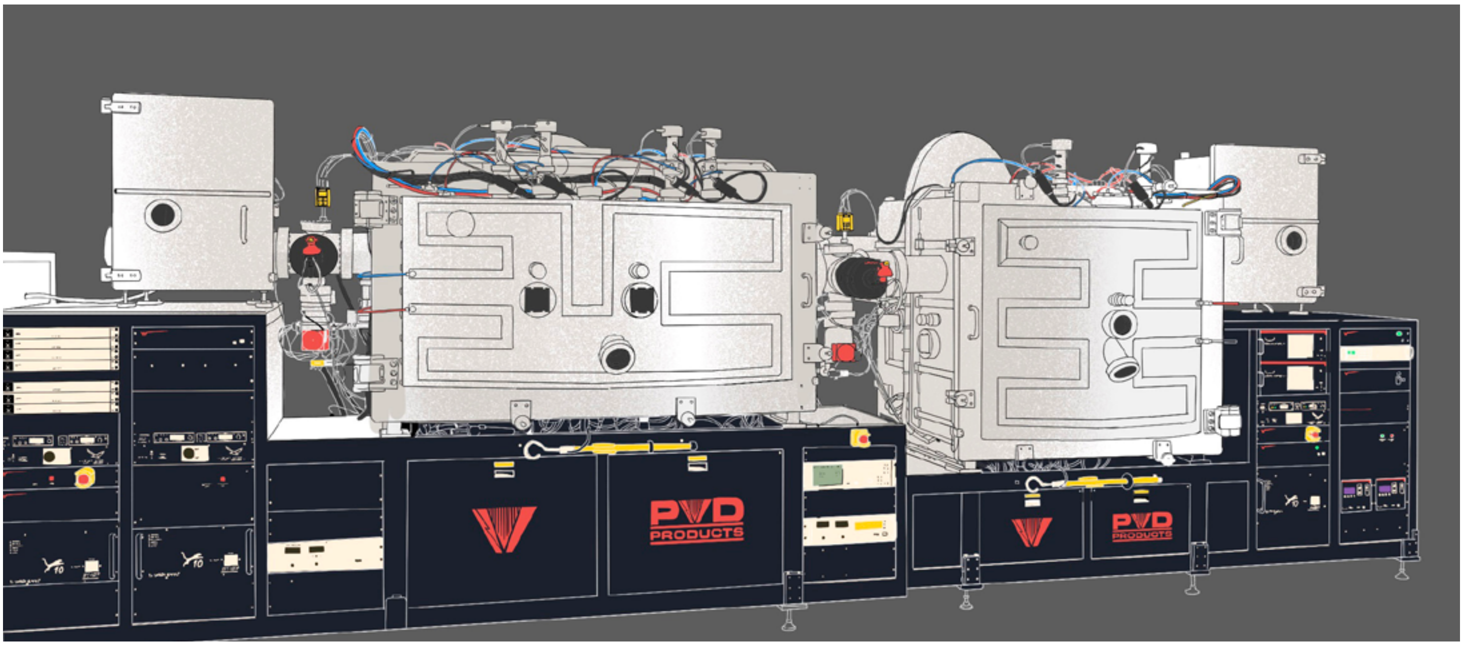


High Speed Reel-to-Reel IBAD/Homo Epi Deposition System

PVD Demonstrates MgO Depositon at 350 m/hour for 12-mm Wide Tapes

Researchers with PVD Products and S-Innovations have demonstrated the deposition of high quality MgO buffer layers at tape at speeds of 350 m/hour for 12 mm wide tapes. Subsequent growth of ReBCO shows excellent morphology and an I_c of 550 A at 77 K at self-field for 6 meters of tape. The design of the system is such that one could run a single lane of 100 to 120 mm-wide tape at about 100 m/hour with similar results, yielding a huge increase in throughput for this process.

The improved deposition rate could have a huge impact on the cost of HTS coated conductor (CC) tapes and the supply of such tapes for fusion and many other HTS applications. The higher deposition speeds could lead to a 10% reduction in the price of tape; the exact size of the drop in price will depend on a number of factors.

CC Production Rate Increases Needed for Small Fusion Reactors

Recent interest in high field electromagnets to be used in designs of small fusion reactors equipped with HTS electromagnets has put significant pressure on CC tape manufacturers for increases in production rates of ~ 10 x/year for high quality HTS tapes. The amount of tape needed just to build a single demonstrator reactor outstrips, by an order of magnitude, the present worldwide capacity to produce tape.

Higher speed tape manufacturing has thus become a critical need. In particular, work on compact fusion reactors by Commonwealth Fusion Systems (see *Superconductor Week*, Vol 34, No 10) and Tokamak Energy (see *Superconductor Week*, Vol 33, No 6) is driving the need for orders of magnitude of more tape per year than that currently available.

MgO Buffer Layer Deposition Key Bottleneck

One of the key bottlenecks in production of CC tapes is the epitaxial MgO buffer layer deposited one or two steps before the ReBCO superconductor, depending on the particular process used. In the widely-used Stanford process, ion beam assisted deposition (IBAD) produces the biaxially textured template for the subsequent addition of epitaxial MgO (EPI) by electron beam evaporation on heated substrates.

The IBAD growth rate is limited by the available ion beam flux, which must match the arriving flux of MgO molecules at the tape substrate. To date, typical

‣ Stanford-type process tools have been able to deposit MgO films at a rate of about 80 to 120 m/hour for a 12 mm wide tape.

“Our goal is to provide deposition systems that significantly increase the throughput without degrading film quality,” said James Greer, President of PVD Products. “This still is the 'Stanford' Process, just with larger deposition zones which allows for faster tape speed.”

System can Process 1.0 km of 100 µm-thick at 200 m/hr

PVD has developed and commercialized a dual-chamber system for high-speed production of IBAD/EPI layers. The system can process 1.0 km of 100 µm-thick tape at a speed of 200 m/hr. Longer lengths of thinner tape are possible due the high capacity electron beam sources.

The system features extended length deposition zones with multiple tape passes and a unique IBAD geometry pairing one evaporator with two large rectangular RF ion sources. The EPI layer chamber is likewise equipped with dual evaporation sources to support growth of thick EPI MgO at high processing speed. Multi-pass deposition handles 12-mm wide tape, and the tool is also designed to handle a single lane of 10 cm wide tape, albeit at a lower tape speed of ~50 m/hour.

Two dedicated, differentially pumped RHEED chambers provide real-time feedback on film quality of both the IBAD and EPI processes without exposing the RHEED system to evaporant or high gas pressure. The tool has demonstrated processing 1.0 km of tape in a continuous 5-hour run.

“The dual ion sources and dual ebeams allow us to increase the size of the deposition zones, thereby increasing tape speed,” said Greer. “We are comfortable with 100 mm wide tapes at the present.

“It may be possible to go to 120 mm wide tapes with current technology. Going wider than this would require significant ion beam development in order to achieve the uniformity of ion to neutral flux over the tape width.”

System Includes IBAD, RHEED Analysis, EPI Chambers

The first step in PVD's deposition process involves winding 300-m long, 12-mm wide by 0.1-mm thick Hastelloy tapes with appropriate amorphous oxide buffer layers on spools. These are then placed inside of the payout chamber. The tape is continuously pulled into the IBAD chamber, where MgO is evaporated and the substrate area is bombarded from a pair of rectangular RF ion sources.

The tape then enters a RHEED analysis chamber to monitor the crystalline quality in real-time. Upon leaving the RHEED chamber and entering the EPI chamber, the tape undergoes heating to ~600°C while MgO is deposited via evaporation from two ebeam sources. The tape leaves the Homo-Epi chamber and enters a second RHEED chamber for further real-time analysis, and then gets spooled back on a take-up reel.

For the recent study, PVD selected a wide variety of tape speeds and process parameters in a combinatorial mode to find deposition parameters that produce high quality MgO layers. After deposition, x-ray diffraction (XRD) was conducted to evaluate the MgO crystaline quality of the tapes grown under differing conditions. A final buffer layer of ~40 nm of $LaMnO_3$ was then reactively magnetron sputtered onto the tapes using a pulsed DC power supply.

ReBCO films were then deposited via the PLD process to a nominal film thickness of 2.2 microns. An Ag layer was sputtered on top of the ReBCO film prior to testing for I_c. The key innovations in PVD's new system include the use of two ion sources installed in a unique fashion and the deployment of dual ebeams in the EPI chamber.

IBAD Chamber has Seven Lanes of ~100-mm Wide Tape

The system's IBAD chamber has a multi-pass set up with seven lanes of ~100-mm wide tape. The chamber has a deposition zone length of 30 cm and contains two 6 x 22 cm RF ion sources. Each of the RF ion sources has three MFC's ion beam mapping capability with modular Faraday cups on a programmable x-y stage single ebeam gun with a 1,486 cc trough and a 10 kW power supply operating at -7 kV. Additionally, the chamber features two JEOL 12 crystal sensor heads and two CTI 400 cryos on a large tee.

▸ Three Faraday Cups are mounted on programmable x-y stage to map out beam current uniformity within the deposition zone. The devices are capable of mapping out a complete profile in about 20 minutes. This allows the user to obtain data for many different beam and grid voltages, gas flows, etc. for a fixed position ion source configuration without breaking vacuum.

EPI Chamber has Deposition Area for 12 Lanes of 50-cm-long Tape

The EPI chamber contains a multi-zone high temperature heater with deposition area for 12 lanes of 50-cm-long tape for the epitaxial growth of MgO. It deploys two ebeam sources each with 1,486 cc troughs. It also features 4 JEOL 12-crystal QCM heads and two CTI 400 cryos on a large tee.

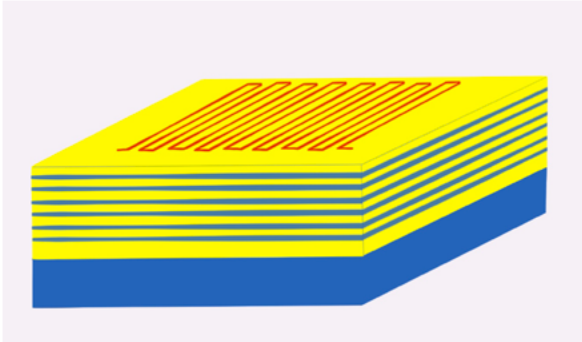
The system also incorporates two RHEED chambers, each with its own pumping package to keep the pressure in the low 10-6 Torr range. A STAIB 35 keV RHEED gun with a k-Space DAS were used to obtain continous RHEED image.

"As an equipment vendor we don't have the luxury of keeping tools on the floor for long periods of time," said Greer. "Thus, the results presented here are our first attempt at growing MgO films under various deposition conditions without any feedback loop.

"It is likely that this system could run at 500 m/hour or more with similar results for 12 mm wide tape. It could also process 2 km or more tape in one complete run. We have shipped one high-speed unit, and we are talking to several companies about IBAD and other related systems.

"We also have designs for a complete buffer layer multi-chamber system starting from Al_2O_3, Y_2O_3, MgO, LMO that should be able to run at 200 to 300 m/hour. The oxide deposition is currently the largest bottleneck in the process flow."

PVD Products, Inc. is a manufacturer of custom thin film deposition systems, reel-to-reel deposition equipment for the coated-conductor market, and combinatorial deposition tools for rapid process development. The company is based in Wilmington, MA. S-Innovations is a developer of HTS wire for different applications based in Moscow. ■



SIMIT Builds SNSPD with Optimal Detection Efficiency

Researchers from the State Key Laboratory of Functional Materials for Informatics of the Shanghai Institute of Microsystem and Information Technology (SIMIT) have developed a niobium nitride (NbN) superconducting nanowire single-photon detector (SNSPD) with record system efficiency of 0.98 by replacing a single-layer nanowire with twin-layer nanowires on a dielectric mirror (doi.org/10.1364/OE.410025). The detector may be suitable for quantum information applications and is of practical significance for batch production.

"This type of detector may help to increase the yield of SNSPD with high efficiency," commented Professor Hao Li of SIMIT. "For quantum computation, the performance is proportional to the η^n, where η is efficiency and n is the qubit number.

"When n is large, we may see that even a 1% improvement is a huge difference. For example, n=100, if η increases from 0.9 to 0.98, the performance will be 5000 times better."

NbN SNSPDs Have Lower Kinetic Inductance and Higher Critical Current

Single-photon detection enables numerous applications in modern physics, chemistry, biology, and astronomy. However the technology has not kept pace with the rapidly advancing field of quantum information and technology, which requires detectors with near-unity efficiency for numerous quantum fundamental theory verifications and quantum information applications.

▸ The detection efficiency of conventional SPDs, such as avalanche photodiodes and photomultiplier tubes, is hampered by limited bandgap energy. SNSPDs are more promising, offering high system detection efficiency (SDE) because of their small Cooper-pair breaking energy. These detectors using tungsten silicide (WSi) or molybdenum silicide (MoSi) as a superconductor have demonstrated SDEs of 93%, but suffer from low time resolution and low speed due to their relatively low T_C's.

NbN SNSPDs offer a more practical solution for applications at near-infrared wavelengths, since they usually have a lower kinetic inductance and a higher critical current than WSi or MoSi SNSPDs, which results in a higher speed and a lower timing jitter. To date, NbN SNSPDs with higher T_C's have shown slightly lower SDEs. Further improving the SDE for NbN SNSPDs requires near-unity photon-response probability and absorption simultaneously for the nanowire with a finite filling ratio, which is limited by the coupled relations between these two factors via the superconducting nanowire.

Improving SDE has been attempted by employing a thick nanowire for the increased absorption length. This has resulted in a higher T_C and thus a low photon-response probability.

SIMIT Sandwiched Insulator Between Two NbN Nanowires

The SIMIT team tried a different approach. They sandwiched a very thin insulating layer between twin NbN nanowires. This structure decouples photon-response probability and absorption so that optical absorption is increased while retaining absorption due to the insulation in between. When combined with a lossless dielectric mirror, photon-response probability and absorption were capable of reaching nearly 100% simultaneously, thus enabling practical SNSPDs with optimal SDEs and a high yield.

The researchers fabricated the detector on a silicon wafer. They alternatively deposited quarter-wave optical film stacks composed of 13 periodic SiO_2/Ta_2O_5 bilayers with a central wavelength of 1550 nm onto the Si substrate using ion beam assistant deposition, and the film thickness was optically monitored to ensure adherence to the designed layer thickness.

A 6-nm-thick, 75-nm-wide NbN layer was deposited on the substrate at room temperature using reactive DC magnetron sputtering in a mixture of Ar and N_2 gases. The team then deposited a thin 3-nm insulating layer of SiO_2 on the NbN film via plasma enhanced chemical vapor deposition.

The top 6-nm-thick layer of NbN was deposited via the same process as the bottom NbN film. A bridge was then etched by the reactive ions to form the co-plane waveguide for the readout of electrical signals.

Detectors Demonstrated High Speed and Robustness

When tested, the detector at 0.8 K showed a maximal system detection efficiency (SDE) of 98% at 1590 nm and a system efficiency of over 95% in the wavelength range of 1530–1630 nm. Moreover, the detector at 2.1 K demonstrated a maximal SDE of 95% at 1550 nm using a compacted two-stage cryocooler. The detector also showed the robustness against various parameters, such as the geometrical size of the nanowire and the spectral bandwidth, enabling a high yield of 73% (36%) with an SDE of >80% (90%) at 2.1 K for 45 detectors fabricated in the same run.

"Actually, 50 detectors in total [were fabricated] but only 45 detectors were measured," Li said. "This detector number can be easily scaled using a larger wafer. To date, there are no reports about batch production of WSi or MoSi SNSPDs."

The research received funding from the National Key Research and Development Program of China (2017YFA0304000), the National Natural Science Foundation of China (61671438, 61827823, 61971408), the Shanghai Municipal Science and Technology Major Project (2019SHZDZX01), the Shanghai Rising-Star Program (20QA1410900), the Program of Shanghai Academic Research Leader (18XD1404600), and the Youth Innovation Promotion Association of the Chinese Academy of Sciences (2020241). ■

DOE Awards SBU $2.4 Million for Superconducting Fusion Power Development

The DOE's Advanced Research Projects Agency-Energy (ARPA-E) has awarded Stony Brook University (SBU) $2.4 million to improve the effectiveness and longevity of shield materials for HTS fusion magnets. SBU's "ENHANCED Shield: A Critical Materials Technology Enabling Compact SC Tokamaks" project is one of 14 that received funding as part of the Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts (GAMOW) program. The University of Houston separately received GAMOW funding to develop low-cost HTS materials with improved I_C's above 20 K (see *Superconductor Week*, Vol 34, No 9).

GAMOW Program to Develop Enabling Technologies for Fusion Power

Recent investments in the development of fusion energy have been focused on the development of a viable and net-energy-gain fusion-energy system. However, there remains a significant need to focus on the materials and enabling technologies that will be needed to establish fusion energy's technical and commercial viability once net energy gain is achieved.

GAMOW teams will work to close multiple fusion-specific technological gaps that will be needed to connect a net-energy-gain fusion core, once it is ready, to a deployable, commercially attractive fusion system. Projects will address one or more R&D categories, including technologies, materials, and superconducting-magnet and fuel-cycle subsystems between the fusion plasma and balance of plant; cost-effective, high-efficiency, high-duty-cycle, electrical-driver technologies; and cross-cutting areas such as novel fusion materials and advanced and additive manufacturing for fusion-relevant materials, components, and their cost-effective scale-up.

GAMOW projects will operate in synergy with both publicly and privately funded fusion-development efforts, including ARPA-E's ALPHA and BETHE fusion programs. ARPA-E and SC-FES will jointly fund the projects over the $29 million program's three-year lifespan. The $2.4 million grant awarded to SBU is for the full three-year period, and it is accompanied by an additional $235,000 in-kind contribution from the university.

"This program is led by SBU with partners Massachusetts Institute of Technology and the University of Tennessee Knoxville," said Professor Lance Snead of the College of Engineering and Applied Sciences at SBU, the Principal Investigator on the GOMOW grant. "The team will work in collaboration with both Commonwealth Fusion Systems and Tokamak Energy, who are members of our Advisory Board."

SBU to Develop Composites to Protect HTS Fusion Magnets

As part of the ENHANCED Shield project, SBU researchers will leverage innovative manufacturing methods to fabricate novel two-phase composites that simultaneously moderate and absorb neutrons while attenuating gamma radiation. The new class of shield is comprised of highly absorbing metal hydrides entrained within an irradiation-stable ceramic matrix.

These composites, which can operate at high temperatures, possess hydrogen density approaching that of water with a high and adjustable absorption amount. The proposed shield materials' advantages over present technology include enhanced neutron-absorbing capabilities allowing for thinner shields, engineered radiation tolerance, high-temperature stability, and long component lifetimes, eliminating the need for shield component replacement.

The new shield material could potentially reduce the radial-build size of fusion power plants by a factor of two and increase magnet lifetimes. The size reduction of the overall facility and the extended lifetime of the magnet provide compounding reductions on the levelized cost of energy.

"The specific goals of this program are to demonstrate the manufacture of representative curved composite shield plates of significantly enhanced performance as compared to current technology," said Snead. "The threat to the inboard high temperature superconductor due to irradiation is both damage to the HTS crystal structure caused by neutron cascades, and volumetric heating caused by ionizing radiation.

"Current magnet shield solutions in machines such as ITER include borated steel. Here we aim to fabricate a new class of high-temperature and simultaneously neutron-absorbing and moderating shields which outperform current shield solutions in terms of damage and heating to the HTS magnet by an order of magnitude on an equivalent thickness basis."

Improved Shield Could Significantly Extend Magnet Lifetime

"While our team will pursue nominally lower temperature, lower-performance metal matrix composites (meaning entrained metal hydrides within a composite matrix of a metal of low hydrogen diffusivity), the assumed high-performance ENHANCED shield will be our ceramic matrix composite," said Snead. "This technology has been enabled through a breakthrough made in a parallel MEITNER program that is also SBU-led.

"That program was able to significantly reduce the processing temperature for MgO through both use of advanced manufacturing (direct current sintering aka Spark Plasma Sintering) and the addition of a fugitive sintering aid of fluoride salt, in this case <1% LiF. In this process the temperature to densify MgO is reduced from well over 1200°C to <800°C. As high-temperature hydrides begin to decompose at <900°C, this breakthrough has allowed us to process MgO with some entrained hydride.

"Currently, the lifetime of HTS magnets as degraded by neutron damage is not well understood. However, assuming a behavior similar to their low-temperature cousins which have a relatively low allowable neutron dose, the reduced size of the ENHANCED shield allows for a trade-off to be made between magnet lifetime (potentially allowing for a lifetime component) versus shield thickness. In effect, we will be able to improve reactor economics by reducing the radial build."

Project must Overcome Critical Challenges

"There are two critical challenges," added Snead. "The first is the ability to fabricate a useful and economic composite product.

"Similar work under our MEITNER project suggests a clear path to success in this area. The second is the unacceptable loss of hydrogen from the composite from long-term thermal diffusion through the matrix. These losses are possibly enhanced by irradiation." ■

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U Rochester-led Team Achieves T_C of ~288.7 K at 267 GPa in Carbonaceous Sulfur Hydride

Researchers with the University of Rochester, the Intel Corporation, and the University of Nevada have reported superconductivity in a photochemically transformed carbonaceous sulfur hydride system, starting from elemental precursors, with a maximum T_c of 287.7 ± 1.2 K achieved at 267 ± 10 GPa. The research was supported by the NSF under grant number DMR-1809649 and via the DOE Stockpile Stewardship Academic Alliance Program under grant number DE-NA0003898. The study received additional support from the U.S. DOE, Office of Science, Fusion Energy Sciences under award number DE-SC0020340.

Research Aims for Room T_c Superconductivity in Superhydrides

"This study is part of my NSF grant, with which I proposed to study ternary superhydrides," said Ranga Dias, Assistant Professor at Rochester and co-author of the research. "The goal of the project to discover room temperature superconductors in superhydrides.

"At a pressure of 267 GPa, I can't think of any applications [for this material]. However, the progress on novel hydrogen rich materials at high pressures with room temperature superconductivity will lead us to greater clarity in a superconducting mechanism. In turn, it may allow us to obtain insight into designing new superconducting materials in large quantities at ambient pressure.

"The challenge of high pressure superconducting materials is to produce materials that are stable, or metastable, at ambient pressure via 'compositional tuning' so that they will be even more economical to mass produce. Introducing an element that can form strong bonds that do not break apart when pressure is released is one possibility. Carbon would form such strong bonds."

Study Builds on Previous Work to Develop Hydrogen-rich HTS Materials

The study builds on previous work that realized HTS in several hydrogen-rich materials under high pressure. An important discovery in the development room-T_c superconducting materials was the pressure-driven disproportionation of H_2S to H_3S, which resulted in a confirmed T_c of 203 K at 155 GPa.

Both H_2S and CH_4 readily mix with hydrogen to form guest–host structures at lower pressures, and are of comparable size at 4 GPa. By introducing methane at low pressures into the H_2S + H_2 precursor mixture for H_3S, molecular exchange is allowed within a large assemblage of van der Waals solids that are hydrogen-rich with H_2 inclusions; these guest–host structures become the building blocks of superconducting compounds at extreme conditions.

Researchers Observe Sharp Rise in T_c Above 220 GPa

In the recent study, researchers observed the superconducting state over a broad pressure range in a diamond anvil cell, from 140 to 275 GPa, with a sharp upturn in T_c above 220 GPa. The team observed zero resistance with a magnetic susceptibility of up to 190 GPa and a reduction of the T_c under an external magnetic field of up to 9 T. The researchers measured an upper critical magnetic field of about 62 T according to the Ginzburg–Landau model at zero temperature.

"The photochemical route to make our starting framework of hydrogen-rich species is novel," said Dias. "It has never been used before in high pressure experiments. This is critical in introducing methane and hydrogen sulfide into the starting material, that allows just the right amount of hydrogen needed for such remarkable properties."

The light, quantum nature of hydrogen limits the structural and stoichiometric determination of the system by X-ray scattering techniques, but the research team was able to use Raman spectroscopy to probe the chemical and structural transformations in the material prior to metallization. The introduction of chemical tuning within a ternary system could enable the preservation of the properties of room-temperature superconductivity at lower pressures.

Researchers Found New Company, Unearthly Materials

The researchers have started a new company, Unearthly Materials, with the goal of finding a path to room temperature superconductors that could be scalably produced at ambient pressure. Dias elaborated on how the company aimed to achieve its goals: "We do not know the exact stoichiometry, in other words how many C, S, H atoms there are in the primitive description of the material at Mbar pressures.

"We have some idea but don't know the exact answer. We also don't know the structure. Because of the light mass of the material, it prevents us from doing x-ray diffraction.

"We have been developing a new set of tools to solve this problem. Once we have answers to those questions, we can find a way to make it at ambient pressure via compositional tuning. At the moment, our primary collaborator is the University of Rochester. We are currently in the process of acquiring licenses from the University." ■

Strong SPS Revenues Contribute to AMSC Q2 FY2020 Results

AMSC has announced in its Q2 FY2020 earnings release that Grid unit revenues rose by 42.3% to $16.3 million, compared to $11.5 million in revenues realized in Q2 FY2019. The net operating loss of the segment was $1.4 million, compared to a loss of $1.3 million the previous year. Two Grid business lines, superconducting Ship Protection System (SPS) and non-superconducting D-VAR, were the primary drivers of this revenue increase although the two additional lines, superconducting Resilient Electric Grid (REG) and non-superconducting VVO, also contributed.

For the first half of FY2020, Grid revenues increased by 59.6% to $34.1 million from the $21.3 million achieved during the first half FY2019. The net operating loss declined to $2.6 million compared to a loss of $6.0 million for the comparable period last year.

"At the halfway mark of the fiscal year, our Grid business is performing at a very high level," commented Daniel P. McGahn, Chairman, President and CEO of AMSC, during the quarterly earnings conference call. "We've been delivering against a strong backlog of grid orders, which not only includes D-VAR orders, but also SPS, VVO, and our REG order."

AMSC has Three Orders for Deploying SPS

McGahn highlighted the strong contribution of SPS to Grid segment revenues. SPS for the San Antonio class should represent approximately $10 million of revenue per vessel. AMSC currently has three orders for deploying SPS on LPD 28, LPD 30 and LPD 31, and is working with the Navy to understand the program timing for LPD 29.

"From a capacity perspective, we've been planning for the concurrent manufacturer of multiple SPS orders," McGahn said. We anticipate SPS has the potential for deployment on the Navy's planned 15 additional San Antonio-class ships. Our SPS could represent a potential revenue stream of up to $150 million for this class of ship."

Chicago REG Project Proceeding on Schedule

McGahn also provided an update on the REG system project with ComEd in Chicago, for which construction began in July (see *Superconducting Week*, Vol 34, No 7): "We are delivering hardware to the project; we are providing technical support during construction; we are on-schedule for delivery of the system and anticipate energization in 2021 per ComEd schedule. With the first system secured, we believe that future deployments of REG will be derisked. U.S. utilities are focused on our execution of this first Chicago project.

‣ "AMSC and ComEd have also proceeded with the engineering assessment of a proposed second REG system in Chicago. This second project, if agreed to and undertaken, would interconnect multiple existing substations in Chicago's central business district. The second project is expected to be larger in scope than the first, and provide greater reliability, resiliency and load-serving capabilities during outages, as well as other grid disruptions."

Total Revenues Increase for Quarter

For Q2 FY2020, AMSC's aggregate revenues, which include its Wind unit, rose by 50.7%, to $21.1 million from $14.0 million in Q2 FY2019. The company reported a loss of $3.7 million ($0.17 per share) compared to a loss of $0.8 million ($0.04 per share) last year.

For the first half of 2020, AMSC realized $42.3 million in revenues, 52.4% higher than the $27.8 million in revenues achieved during FY2018. The company reported a net loss of $7.2 million ($0.33 per share) compared to a net loss of $4.4 million ($0.40 per share) during the first half of FY2019.

Cash, cash equivalents and restricted cash at the end of the quarter declined to $57.7 million, compared with $62.2 million at the end of the previous sequential quarter. AMSC's share price advanced by 0.3%, to $14.63 from $14.58, the day after the earnings announcement.

Company to be Cash Flow Positive in Q3 FY2020

For Q3 FY2020, AMSC anticipates that its revenues will be in the range of $22 million to $25 million. Net loss is expected not to exceed $6.0 million, or $0.23 per share.

The company expects positive operating cash flow of up to $1 million. Cash, cash equivalents, marketable securities and restricted cash are expected to be no less than $80 million at the end of the quarter, which reflects the $26 million in cash paid in connection with the acquisition of Northeast Power Systems, Inc. (NEPSI) in early October and the $51.4 million in approximate net proceeds from a stock offering which closed later that month. ■

Bruker BioSpin Revenues Recover in Q3 FY2020

Bruker Corporation's BioSpin Group revenues for the Q3 FY2020 grew by 5.8% to $152.1 million compared to $143.7 million in Q3 FY2019. For the first three quarters of FY2020, revenues dropped by 6.8% to $398.1 million from $422.4 million during the comparable period last year. The company attributed the revenue increase, both year-over-year and sequentially, to the continuing recovery of the academic market and the robustness of the biopharma market.

BioSpin Group operating income is reported by Bruker combined with the CALID Group in the BSI (Bruker Scientific Instruments) Life Sciences segment. This segment reported operating income for the quarter of $80.6 million, 6.5% higher than the $75.7 million realized in Q3 FY2019. For the first three quarters of FY2020, operating income declined by 11.8%, to $158.7 million from $179.9 million for the comparable period last year.

"During the third quarter, BioSpin received customer acceptance for a second 1.2 GHz and NMR system, which was successfully installed at the ETH [the Swiss Federal Institute of Technology] in Zurich, Switzerland," commented Frank Laukien, President and CEO of Bruker, during the quarterly earnings conference call. "BioSpin continues to ramp up its manufacturing and shipment activities for gigahertz systems. During the first nine months of the year, BioSpin's NMR and PCI Systems' revenue declined year-over-year due to delayed order and installation activity, as expected."

Magnet Demand High in Europe but with Funding Problems in the U.S.

Laukien noted that magnet demand has been strong in Europe but has lagged in the U.S. due to funding issues More than ten orders are on backlog in Europe. In the U.S., Bruker delivered a 1.1 GHz magnet to ther St. Jude Children Research Hospital in Memphis, Tennessee and has an order in its backlog for Ohio State University.

▸ "We have a lot of backlog for the next two years and we expect to be at higher than three systems per year,"Laukien said. "We don't want to give 2021 guidance, but as we're looking at three systems this year, we expect that to be higher next year."

BEST Revenues Declining on Weak Superconductor Demand

Bruker's Energy & Supercon Technologies (BEST) segment reported that revenue fell by 16.6%, from $52.5 million in Q3 FY2019 to $43.8 million in Q3 FY2020. Operating income decreased by 67.7% to $1.2 million from $3.6 million. The lower revenue and income were due to weaker superconductor demand and reduced productivity, given the COVID-19 pandemic.

For the first three quarters of FY2020, BEST revenues were $134.8 million, 11.4% lower than the $152.2 million in revenues realized during the first three quarters of 2019. Segment operating income fell by 48.5% to $5.1 million from $9.9 million.

Aggregate Revenues Declined Slightly in Q3 FY2020

For the company as a whole, Bruker announced revenues of $511.4 million for Q3 FY2020, 1.9% lower than Q3 FY2019 revenues of $521.1 million. Growth from acquisitions was 0.3%, while favorable foreign currency translation contributed 2.4%. Net income was $54.3 million ($0.35 per share) compared to $61.3 million ($0.39 per share) over the comparable period, a decline of 11.4%.

For the first three quarters of FY2020, Bruker revenues were $1360.0 million, 7.7% lower than the $1472.7 million realized during the first three quarters of FY2019. Net income was $88.9 million ($0.57 per share) compared to $128.6 million ($0.82 per share) over the comparable period, a 30.9% reduction. Bruker's share price fell by 0.1%, from $44.03 to $43.98, on the day following the earnings announcement.

"We are navigating a challenging environment, with some academic and industrial customers still negatively impacted by the pandemic," Laukien noted. We are nonetheless pleased with our strengthened financial performance in the third quarter, as our non-GAAP operating margin and non-GAAP EPS improved significantly compared to the first two quarters of 2020 and approached our Q3 FY2019 levels."

Financial Guidance Remains Suspended

Cash on the balance sheet was $617.1 million at the end of the quarter, compared to $796.8 million at the end of Q2 FY2020. Cash was used to fund strategic capital investments, acquisitions, dividends and buybacks as well as a revolver debt repayment of $208.5 million.

In Q3 2020, Bruker repurchased 127,000 shares of stock for a total of $5 million, bringing total buybacks year-to-date to 1.34 million shares for $55 million. As of the end of the quarter, $102.7 million remained on the share repurchase authorization, which is valid until mid May 2021.

Bruker's FY2020 financial guidance remains suspended. Given the continued COVID-19 pandemic, CFO Gerald Herman explained that the company is considering a range of scenarios for Q4 FY2020, with the potential for a revenue decline of between 2% and 6% year-over-year, compared to a strong Q4 2019. These projections include revenue from one ultra-high field GHz class system, which is not tied to a specific country since multiple systems that are in various stages in the installation process. ■

ASC 2020 Virtual Conference a Success

The 2020 Applied Superconductivity Conference, to be held in July in Tampa, Florida was initially announced at the 2018 Seattle conference. Little did the organizers know that they would then be dealing with a pandemic that would force them to move to a virtual setting four months later, with a much longer duration of October 24 - November 7, 2020.

Conference Chair and President Lance Cooley, the director of the National High Magnetic Field Laboratory's (MagLab) Applied Superconductivity Center, noted that the conference theme, "Horizons in Clear View", initially reflected the Tampa location, next to Clearwater Beach, which faces westward over the Gulf of Mexico, with a limitless horizon and beautiful sunset. Since Tampa is also known for pirates, the theme also paid homage to the "Pirates of the Caribbean" film, whe Captain Jack Sparrow grabs the wheel of the Black Pearl and says, "Now, bring me that horizon!"

Virtual Conference Created Unusual Challenges

Once it became clear that the conference had to become virtual, the theme was seen as capturing the spirit of superconductivity technology development. Since this is the year 2020, it also connected to 20/20 vision and its connotation of focus and clarity. Areas receiving this focus included quantum information, fusion, magnetic resonance, room-temperature superconductivity, and particle physics and cosmology beyond scales previously imagined.

"Probably the greatest challenge was having to pull the virtual conference together with very little time or experience and the full reputation of the conference on the line," Cooley noted. "Everything was one grand experiment.

"Part of the challenge arose from what the organizing team chose as requirements for the virtual meeting. The team decided that the in-person program should largely be retained, which meant that we had to fit the virtual platforms to the conference program and not the other way around.

"Time zones and the fact that 2/3 of the conference was not in the Americas forced an extension of the program to two weeks and restricted 'live' activities to a limited three hour slot each day. This strategy helped keep daily 'Zoom time' below four hours, which was another requirement."

Plenary Speakers Covered the Field

The plenary speakers covered a variety of topics. Max Planck Institute for Chemistry researcher Mikhail Eremets opened ASC 2020 with a presentation about room temperature superconductivity. Neil Mitchell of ITER gave an update of developments involving that fusion project

Pierre Vedrine of the CEA Paris-Saclay Neurospin Center introduced his institution's 11.7 T whole-body MRI magnet. Fabiola Gianotti of CERN discussed the challenges of particle physics at accelerators.

Joanna Long of MagLab offered a biomedical perspective of ultra-high field superconducting magnets for NMR and MRI. William Oliver of the Massachusetts Institute of Technology spoke about engineering superconducting qubits and quantum computing.

While ASC and ESCC conferences generally have a student component, this feature was more pronounced at ASC 2020, with the establishment of ELEVATE, to integrate student, training, diversity, rising professionals, and related activities into a new platform. ELEVATE is to become a permanent activity integrated into future conference programs and will include events during interim periods between conferences.

Awards Recognized Superconductivity Advancements

As is typical at an ASC or ESCC conference, prizes were awarded. First prize for the Jan Evetts SUST Award went to Xidian University lecturer Ze Jing for his work in recognizing the mechanics-relevant behaviours in superconductors

The second Jan Evetts SUST award was given to EPFL Swiss Plasma Center researcher Nikolay

▸ Bykovskiy, for his work on ReBCO and Nb_3Sn high current conductors for fusion. The third award was to Ohio State University student Feng Wan, who is designing multifilamentary MgB_2 strands having high engineering current density using vapor-solid reaction and C/Dy_2O_3 co-addition for future turboelectric aircraft.

Additionally, two IEEE awards were given for continuing and significant contributions in the field of applied superconductivity to Pasquale Fabbricatore of the Italian Institute for Nuclear Physics, (INFN) and Akira Fujimaki of Nagoya University. Fabbricatore was recognized for his work with superconducting magnets while Fujimaki was cited for his accomplishments with small scale superconductivity applications.

There were two awards for the IEEE Dr. James Wong Award for Continuing and Significant Contributions to Applied Superconductor Materials Technology. Martin Rupich, the senior technical manager of materials R&D at AMSC, was recognized for his work on materials research. Yasuhiro Iijima of Fujikura Ltd. was honored for his work on HTS wire. Elie Track received the Max Swerdlow Award for Sustained Service to the Applied Superconductivity Community due to his work as the Program Manager for Superconductivity at the US Air Force Office of Scientific Research (AFOSR).

Shieh-Yueh Yang received the IEEE Council on Superconductivity Carl H. Rosner Entrepreneurship Award for founding MagQu Co., Ltd. and commercializing SQUID-IMR ac magnetosusceptometers. Student awards went to Enrico Felcini, CERN, working on medical applications; Gleb Krylov, University of Rochester, who is seeking to develop novel approaches for control and readout of qubits; Jun Ma, University of Cambridge, who is working on HTS high field magnet and HTS medical applications; Miranda Thompson, University of Colorado, developing a more comprehensive understanding of Josephson junction barrier physics; Andrea Alimenti, Roma Tre University, for his work on high frequencies characterization methods; and Farzad Faramazi, Arizona State University, for seeking to imulate, design and fabricate a dual-purpose superconducting circuit that can operate as an on-chip Fourier transfer spectrometer and a traveling-wave kinetic inductance parametric amplifier.

"I really think that the pandemic has forced the applied superconductivity community to come together in a common cause, and this spirit has been evident in the congratulatory comments that we have received," Cooley noted. "I would say that we did indeed succeed at bringing many horizons into clear view." ■

Penn State and MagLab Pioneer Method to Raise T_c of α-Mo_2C

Researchers from Pennsylvania State University and the National High Field Magnetic Lab (MagLab) have uncovered a new method for increasing the T_c of molybdenum carbide (α-Mo_2C) by layering it with 2D molybdenum sulfide (H_2S) (doi.org/10.1073/pnas.2003422117). The discovery may provide a new tool for increasing transition temperatures and may constitute another step towards room temperature superconductivity.

"This work is part of a broader research program that is supported by the Department of Energy," explained Professor Susan Sinnott, the head of the Materials Science and Engineering Department at Penn State. "It is focused on using a combination of computation, controlled synthesis, and state-of-the-art characterization to reproducibly produce metastable, hybrid, two-dimensional structures of transition metal dichalcogenides (TMDs) and transition metal carbides (TMCs) that have unique properties."

Heterostacks Formed Using Gas-phase Ruction Approach

Molybdenum is a transition metal found in various oxidation states in minerals. It has a very high melting point and, in its compound carbide form, is used in high-strength steel alloys and superalloys.

"Some phases of α-Mo_2C are superconducting and we have discovered a process by which we can produce hybrid, 2D structures of TMDs and TMCs where the metal in each layer is molybdenum," Sinnott noted. "The goal was to produce vertical and in-plane heterostructures of 2D materials with differing electronic properties, which in this case were superconducting and semiconducting materials or superconducting with possibly topological semimetals with the hope of stabilizing a novel type of superconductivity. The experimental process consisted of exposing platelets of a phase of α-Mo_2C to H_2S at 600 C."

The researchers developed a gas-phase ruction approach that induced the formation of vertical heterolayer systems consisting of different phases of molybdenum carbide, ranging from α to γ' and γ phases. With the added H2S layers, the T_c of α-Mo_2C was raised from 4 K to 6 K, a significant 50% increase.

"The process produced a vertical hybrid structure of superconducting/semiconducting 2D materials," Sinnott said. "We were expecting to make hybrid structures, but we were not completely sure that the process would work in a controllable manner; fortunately, it did."

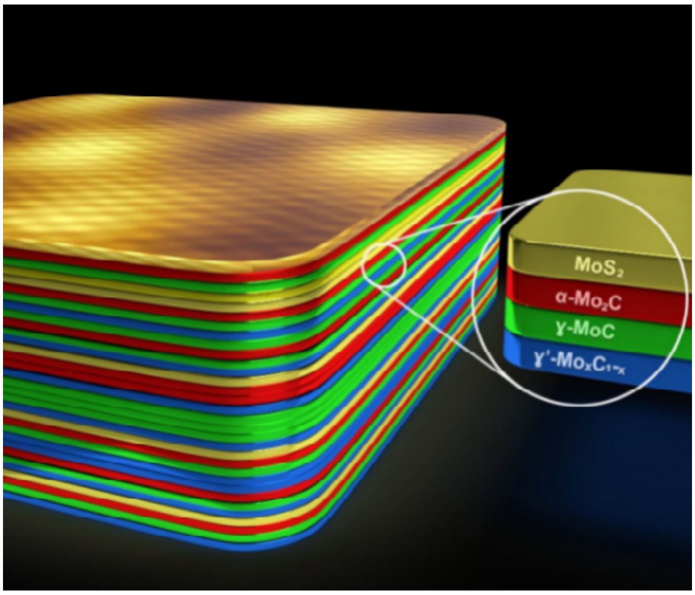
Density Functional Theory Clarified Changes in Material Phases

The team employed modeling techniques to better understand the T_c increase. They ran calculations of density functional theory with implemented quantum mechanics and were able to determine the structures of the buried molybdenum carbide - molybdenum sulfide interfaces.

The researchers theorize that the distinct chemical composition and modified structure of the metastable phase in the layered structure leads to a higher interfacial density of states and increase the frequency of relevant phonon modes, which contribute to superconductivity and result in a higher T_c. "The calculations helped identify the phases of the materials which changed over the course of the plasma treatment," Sinnott summarized. "They also provided insights into the way in which the interfacial details of the hybrid structure influenced the electronic properties of the final material."

Sinnott and her team are exploring how this method might work to raise the T_c of other superconductors: "We are investigating this possibility now with a variety of 2D materials and their combinations. Our objective is to control the kinetics associated with reliably producing metastable, hybrid structures of 2D materials."

Funding for this work was provided by the USDOE, Office of Basic Energy Sciences. ■



Credit: Elizabeth Flores-Gomez Murray/ Penn State

Currents

For its 2020 half-year results, Oxford Instruments plc (OI) announced that its revenues fell by 11.0%, to £143.6 million ($191.0 million) from £157.6 million ($209.6 million) for the comparable half-year period last year. Adjusted operating profit declined by 7.3% to £24.3 million ($32.3 million) from £26.2 million ($34.8 million).

Reported orders were 6.0% higher at £175.7 million ($233.7 million) compared to £165.7 million ($220.4 million) with a book-to-bill ratio of 1.25. The order book reached £204.6 million ($272.1 million), up 16.9% from £175.0 million ($232.8 million) at the end of the preceding six-month period.

Net cash grew to £81.4 million ($108.3 million) due to strong operating cash flow. In response, OI reinstated the dividend that it had suspended earlier in the year (see *Superconductor Week*, Vol 34, No 3). Investors responded by propelling the share price 11.4% higher, to 1,962 pence from 1,762 pence.

"We have seen strong order growth in the first half of the year with a good improvement in the order book," commented OI CEO Ian Barkshire. "Orders have grown across our academic and commercial customer base, particularly for our compound semiconductor process solutions, and quantum cryogenic and magnet systems."

Intel has unveiled Horse Ridge II, its second-generation cryogenic control chip for quantum computing. Horse Ridge II builds on the original Horse Ridge, which was launched earlier this year (see *Superconductor Week*, Vol 34, No 2). The microcontroller uses digital signal processing techniques to perform additional filtering on pulses, helping to reduce crosstalk between qubits.

Horse Ridge II is implemented using Intel 22 nm low-power FinFET technology and its functionality has been verified at 4 K. While this isn't cold enough to support superconducting qubits, Intel has sought to develop silicon spin qubits as a quantum computing alternative. Spin qubits have properties that could allow them to operate at temperatures of 1 K or higher.

The U.S. Department of Energy (USDOE) has established the Center for Quantum Sensing and Quantum Materials, a new research center with the objective of studying the atomic-level processes behind high temperature superconductors, topological insulators, and strange metals. To better probe these materials, the researchers will develop three quantum sensing devices: a scanning qubit microscope, a spectroscopy instrument that takes advantage of pairs of entangled electrons, and another instrument that will probe materials with pairs of photons from the Linac Coherent Light Source. The Center, one of ten USDOE-supported Energy Frontier Research Centers, will be based at the University of Illinois at Urbana-Champaign, and will also include researchers from the SLAC National Accelerator Lab, Stanford University and the University of Illinois-Chicago.

Amazon.com Inc. appears to be laying the groundwork for developing a quantum computer. The company is in the process of hiring a quantum hardware team within its Amazon Web Services (AWS) Center for Quantum Computing, which aimes to bring together researchers from the company and academic institutions to develop new quantum computing technologies. Marc Runyan, a former engineer with NASA's Jet Propulsion Lab, lists his title as senior quantum research scientist at Amazon and describes his role as "helping to design and build a quantum computer for Amazon Web Services."

According to news sources, Amazon's recent hires include research scientists focusing on designing a new superconducting quantum device as well as device fabrication. Developing its own quantum computer would allow the company to more closely mirror the approach taken by its major cloud rivals.

Amazon first entered the quantum computing arena last year in August, when the company launched its first quantum computing service, called Braket. The service helps cloud clients experiment with quantum algorithms run on AWS. Once they've designed their algorithms, clients can choose to run them on quantum processing systems built by other companies.

Fan Zhang, an associate professor of physics in the School of Natural Sciences and Mathematics at the University of Texas at Dallas, has received a National Science Foundation (NSF) Faculty Early Career Development Program (CAREER) award for his quantum physics research. The five-year grant will support his theoretical work and education outreach on the fundamental physics of topological superconductivity.

Zhang's.CAREER award will support novel work on the physical effects of topological superconductivity and materials systems that could bring it closer to reality. In particular, he is investigating how time-reversal symmetry makes Majorana bound states more exotic. In addition, the educational component of this award will allow Zhang to develop dual-level courses on topological quantum matter and create online animated video lessons geared toward boosting physics knowledge among the general public.

The PIP-II Injector Test Facility, PIP2IT, at the U.S. Department of Energy's (USDOE) Fermi National Accelerator Lab (Fermilab) accelerated a proton beam through its new superconducting section for the first time at nearly perfect transmission. PIP2IT is a test bed for Fermilab's upcoming PIP-II superconducting particle accelerator, whose proton beams will reach levels of power not seen before at the lab when it begins operations in the late 1920s.

The PIP-II accelerator, the first major U.S. accelerator project with multinational contributions, will enable the production of intense neutrino beams to the Deep Underground Neutrino Experiment (see *Superconductor Week*, Vol 33, No 7). The 800-million-Ev, 215-meter-long machine will also be capable of sending high-power proton beams of various patterns to other Fermilab experiments.

PIP-II's power and versatility depend on its front section, that initial stretch through which protons are released from the gate and cranked up to about 20% the speed of light, which is why the collaboration established PIP2IT as a test bed for the front section of PIP-II. At this proving ground, researchers will be able to demonstrate concepts and technologies that will be deployed at PIP-II and reduce or remove the related technical risks.

The first day the its team attempted to accelerate a beam through the entire front section, the beam reached an energy of 7.5 million Ev at nearly 100% transmission efficiency. It has since achieved an energy of 9.4 million Ev, solid progress towards an eventual beam energy of about 20 million eV.

PIP2IT consists of two major sections. The first is based on room-temperature technology and includes a radio-frequency quadrupole, which was designed and built by USDOE's Lawrence Berkeley National Lab. The second is based on superconducting radio-frequency technology (SRF) and consists of two cryomodule cavities. The Argonne National Lab designed and built the first cryomodule, known as HWR., while the second cryomodule, known as SSR1, was designed and built by Fermilab and houses an accelerator cavity provided by India's Bhabha Atomic Research Center.

PIP-II is to use "strong-back" technology on four of its five cryomodule types, only the second time the technology is being applied on a superconducting accelerator Strong-back connects each accelerator cavity to a common frame rather than to its neighbor, a structure that keeps the cavities cold yet anchored to a room-temperature frame for easier alignment, less vibration and easy assembly. PIP2IT's SSR1 cryomodule is built as a strong-back, and on-going tests are validating the concept.

In the culmination of seven years of work, the Thomas Jefferson National Accelerator Facility has shipped its final cryomodule to the SLAC National Accelerator Lab for the upgrade of the Linac Coherent Light Source (LCLS), LCLS-II. Once complete, LCLS-II will become the biggest and brightest X-ray free-electron laser in the world.

LCLS-II will provide even better resolution than the original LCLS, which accelerated electrons at room temperature and generated 120 X-ray laser pulses per second. The upgraded machine will accelerate electrons at superconducting temperatures to generate one million X-ray laser pulses per second. Jefferson Lab is a key contributor to the upgrade project, providing a total of 21 cryomodules, including three spares) for the new superconducting portion of LCLS-II since work began in 2013. An additional 19 cryomodules are being fabricated at Fermilab.

Jefferson's work on improving the LCLS may continue with an additional upgrade to the accelerator: LCLS-II HE (High Energy). If that project is greenlighted, Jefferson Lab will build between 10 and 13 more cryomodules that are projected to be better performing than the ones completed for LCLC-II. ■

Spotlight

Paul Grant is an IBM Research Staff Member Emeritus and retired Electric Power Research Institute Science Fellow.

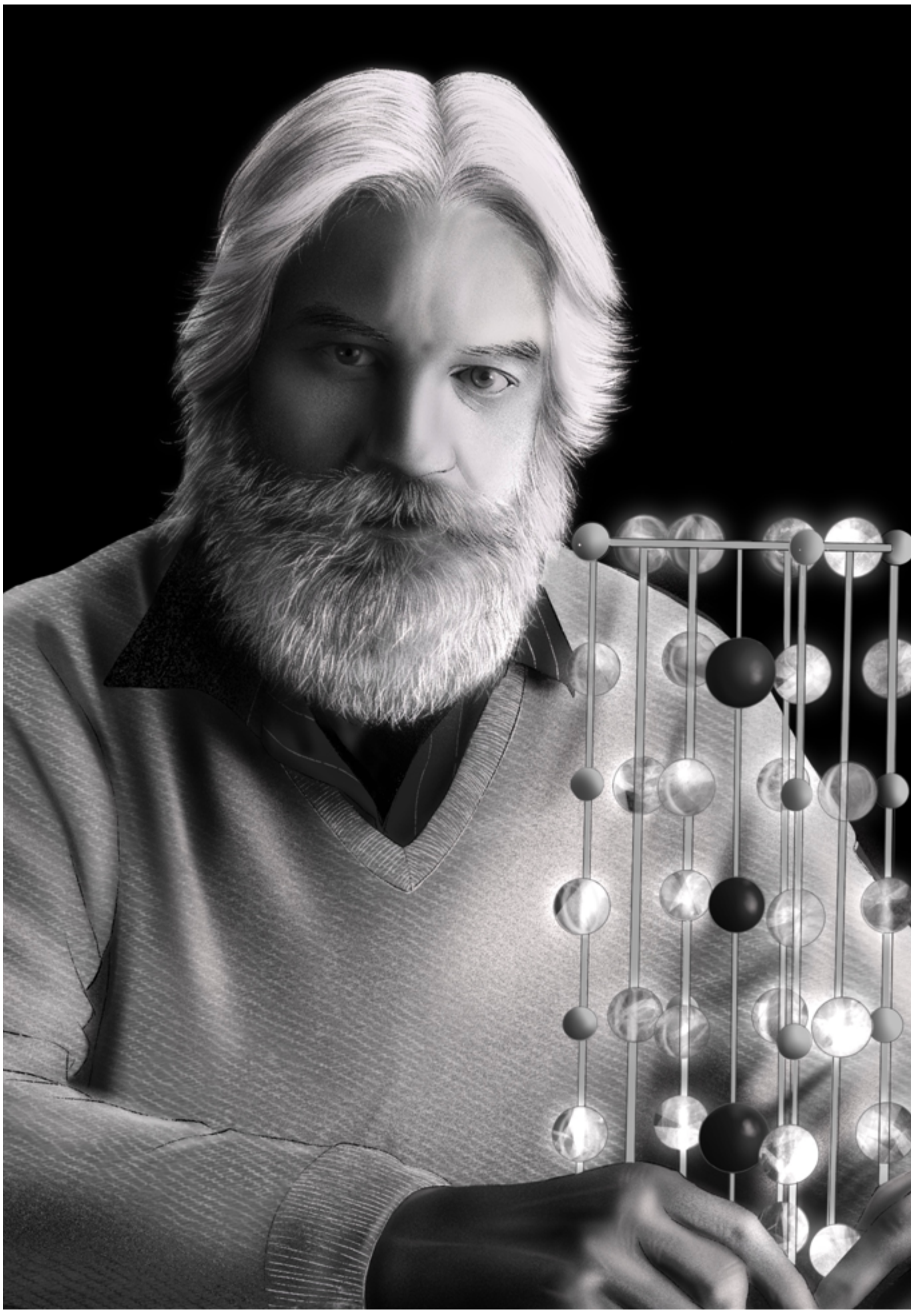
Superconductor Week (SW) : Why don't you start off by telling us about yourself ?

Paul Grant (PG) : Well, let's see. I grew up in the Hudson valley in an IBM family. My dad worked for IBM. My mother was a career woman. She was very political. I'm an only child and I think she was just doing her Irish Catholic duty in having me, but she was really the boss of the family.

On her side, I'm the grandson of Irish immigrants that came over in the 1880s to help dig the sewers in NYC. I was one of four grandchildren that actually were the first to go to high school and get educated. And then all four of us actually went on to obtain advanced degrees in graduate school.

My mom's career started when she was 15 years old as a stenographer at a local utility company, Central Hudson Gas and Electric, later to become one of the major founding utilities of the Electrical Power Research Institute (EPRI). My mother, when she retired, 45 years later, was secretary to the company's CEO. She interacted a lot with attorneys, that's the culture of the regulated utility industry in the United States - in case you haven't noticed. Her ambition for me was to go to Harvard and become a lawyer and it turned out I eventually did go to Harvard but I got a PhD in physics instead, so my mom always considered me the family failure.

I went to work for IBM during my last months of high school, when I was still 17. I started out setting pins in IBM's employee country club bowling alley and when I finally graduated from high school I got promoted, in what turned out to be the biggest break in my life, to be the mail delivery boy in a brand new laboratory that



IBM and the U.S. Air Force had established in downtown Poughkeepsie. It was the first use of computers in an air defense system which became known as SAGE/NORAD - we are talking now in 1952 - so I was trained as a programmer. They found I had some talent for arithmetic.

I was posted out as a member of the SAGE XD-1 prototype service team, organized by IBM and MIT at Lincoln Labs, when I was 19. I had, I like to say, the largest toy in the world to play with, it was the world's biggest computer. When I was 21, IBM decided I was worth educating. They had a program for employees that if you worked in NY state and got accepted to a NY institute or university, and if you studied what IBM wanted you to study, they sent you to college. I thought I'd try it, and I had some difficulty getting accepted because of my miserable high school records my senior year, but eventually Clarkson University in upstate NY accepted me. I went up there under the bar and I was class valedictorian four years later.

▸ When I graduated from Clarkson, I wanted to go to grad school and IBM saw that I was going to quit and they would have lost all their investment in me. It turned out that I got accepted to MIT in the physics graduate program, and when IBM found out that I was going to quit and leave, they said, why don't you go down and talk to this IBM fellow, Rolf Landauer, in Poughkeepsie where the first IBM research lab was built.

Landauer is known for Landauer's Principle from an entropy limit on irreversible computing – when every time a computer switches from a 0 to 1 or a 1 to a 0, the second time around it doesn't remember the state that it was two sets before, so you generate a small amount of entropy. The Landauer Limit has been shown to apply to quantum computers as well.

So Landauer says to me, why the hell do you want to go to MIT, because Harvard is much better in what you want to study, which is solid state physics. I knew that already, but the problem was that I had a national defense education fellowship to attend MIT. Harvard was very anti-militarist in the early 1960s. My national defense education fellowship didn't apply to Harvard, so Landauer convinced IBM to keep me on board as an employee and send me off to what I love to call 'this obscure former divinity school on the banks of the Charles' for my graduate degrees.

IBM had also wanted to know when they sent me to Clarkson what I going to study, and I said I wanted to major in physics. My manager at the time at IBM Poughkeepsie Kingston said, no, we want you to do something useful when you get back here, so you are going to take electrical engineering. So I majored in both. Today, I am one of the advisors on the Clarkson Honors Program, where honors students can get two degrees if they work their asses off and take extra courses and overload themselves. But it was an interesting era. I mean, what other company like IBM today sends employees to school?

SW: It's certainly rarer.

PG: Not out here in Silicon Valley, nowhere that I know of, at least in the United States, so when I got my degree, I escaped from Harvard. IBM had just opened a lab out in California, part of the research division, and I convinced them to transfer me out to the San Jose research lab, so my career has essentially been out here in California.

SW: Was this the same lab where Bednorz and Müller did their research?

PG: No, that's in Zürich.

SW: Is it still an IBM lab?

PG: Yeah, in the 1950s IBM established three labs, one in Poughkeepsie, which was later transferred down to Yorktown Heights; one in Zürich, under the leadership of Alex Müller; and one out in California to essentially do some marketing. But we evolved into hardware development, particularly storage. The research division of IBM was started by someone we called the old man in my time, T.J. Watson, Sr. He was on the board of directors of Columbia University, and he saw that research and engineering in physics could be a valuable asset to IBM, which is why he founded the research division. IBM was a paradigm for the ideal socialistic society, that if you worked hard, behaved, made money for the company, you were taken care of for life - everything, medical, retirement plans, everything, so, that's kind of the culture I grew up in.

SW: Do you think the culture has changed at IBM?

PG: It changed very quickly after IBM had to enter into a compromise of the antitrust suit that had been brought against it by the government in the decades of the 1970s and 80s. You see, the old man would say about IBM, "We sell a service, not machines." and throughout most of IBM's history, throughout the 1950s, IBM owned all of the machines that were in its customers' business sites. They didn't sell the machines, so when you entered into business with IBM, you got the machines sort of for free, and that was considered anti-trust, anti-competitive. Starting in the late 1940s, suits brought by other companies and the government eventually mandated that IBM had to offer their machines for sale, and that's when the company really began to change. In order to economically compete in this new scenario, IBM had to reduce many of the benefits formerly available to its employees.

SW: So you were sent to the lab in California for IBM, what was your primary focus of research over the many years?

PG: My initial work was to continue my thesis work at Harvard, the growth of epitaxial thin films on single crystal substrates, which was brand new at the time.

▸ I started that work at Harvard based upon summer experience I had at Clarkson while working at IBM Kingston. I mentioned magneto-resistive thin films earlier; which earned me and my IBM colleague Bob Penney the first patent on using that effect as memory read-out.

I'm a skier. I'm a mountain guy. My parents taught me how to ski when I was a five-year old in the 1940s, and so when I was in graduate school at Harvard I actually skied on the volunteer ski patrol team at Mt. Snow up in Vermont. I was raising my first family at the time, so my family got to ski for free. My Harvard buddies and I used to fantasize what it'd be like to live in California, where you could go skiing in the morning and surfing in the afternoon, and so that's why I pressured IBM to transfer me to California. That's the basic reason I came out here.

I first heard about superconductivity when I was the mail boy in the Poughkeepsie High Street Lab, the first stage NORAD lab in downtown Poughkeepsie. I was delivering mail and one of the engineers said, hey, kid, come over here; I want to show you something. He took a soldering knife and he splattered some solder, lead tin alloy, of course, on his bench top, scraped it up and wired it up to a current source. He lowered it into a vacuum chamber of really cold stuff - I didn't know what it was at the time, but it was liquid helium, and he measured the resistance going through, and all of a sudden the resistance went to zero, and he said, tell me, what do you think happened? And I said, I think the leads came off, which is stupid because if the leads came off the resistance wouldn't go to 0, it would go to infinity. And he said no, it's called superconductivity.

This engineer became one of my mentors at Clarkson, I worked for him several summers at Kingston. His name was Jim Crowe and he is known as the inventor of the Crowe cell, the first use of superconductivity for computer memory and storage. So that's how I got involved in superconductivity, at a very young age through one of the real pioneers of applications of superconductivity in the digital regime, and then, of course, this is all low temperature stuff.

It was in late 1986 that I heard about an experiment that had been done in IBM's Zürich lab by Alex Müller and his former postdoc Georg Bednorz. I heard about this from one of the people in my department at San Jose Research who had actually visited Zürich and had come back with the news. Alex and I have written about the story in Physics Today and other publications.

There was a lot of competition between IBM's three labs, especially against Yorktown, and I got to know Alex because he was one of the very first IBM fellows and would spend summers with our group in San Jose. And so, this protectionist attitude against Yorktown existed in Zürich as well as in San Jose, but more seriously in Zürich.

And so what did Alex do when he and Georg found zero resistance in an early sample of barium lanthanum copper oxide? They wrote up a manuscript and submitted it to Zeitschrift für Physik. Müller asked its editor not to distribute this paper, but just to read and referee it himself.

Alex had violated a basic tenet of IBM policy in that he did not first publish an internal report, and so I found out about it because one of our at IBM colleagues in San Jose actually came back from a short trip to Zürich and told me. So, at the end of December of 1986, between Christmas and New Year's, I took a quick flight to Switzerland. I didn't tell my managers; I just said I was taking a short vacation. I went down to Zürich, and I went from the airport to the lab. Alex was off skiing; he wasn't there, but I found out where Bednorz' lab was, and I went and talked to Georg and he showed me the experiments.

I carried this back with me, this knowledge, back to San Jose. I didn't inform Yorktown that I found out about what they had been doing, so we were the first group worldwide to replicate Alex's result and it was at IBM San Jose.

SW: Were there any consequences for this insubordination? Long term probably irrelevant because this guy got the Nobel Prize.

PG: Exactly. He got it right away. Alex actually had some friends who were on the Nobel committee, by the way. He had become internationally famous for his basic work on electromagnetism and electrolysis, so he was probably the number one, two or three famous researcher in the general community outside of IBM; he's a great guy .

SW: Wow.

PG: Anyway, that's how we got started in San Jose.

▸ I came back from this trip in the last week of 1986 to Zürich, and that's where the story of HTS superconductivity began in San Jose. There was a lot of internal competition or caution inside IBM about spreading it outside and even inside. Müller did his best to keep everything to himself, and so this affected the initial patent rights to the invention or discovery of high temperature superconductivity, which went to Paul Chu at the University of Houston and the Kitazawa group in Japan. Our group at IBM Almaden Research was awarded the international patent. The whole HTS patent issue will remain unclear until someone finds a real money-making application.

Therefore, I suspect what you may want to talk about is: why isn't superconductivity being used on a large scale?

SW: Yeah, we know where it's being used because we do write about this, and there are a few applications in particular I would like to ask you about. One big question is why haven't there been more applications of HTS wire in power transmission? There are some examples of that happening, most notably AMSC and ComEd's collaboration in Chicago and THEVA's project for power distribution in Munich, which we discussed with their CEO in our last issue. But not such large scale or universal efforts.

PG: I'm aware of all of these. We actually worked with AMSC to use their wire, a distribution cable, which ran from Detroit Edison's rural substation to downtown Detroit, and it all works. And one of the issues that comes up from time to time is why isn't it being more widely applied in the power industry? My offhand opinion has always been that it's because of the utilities.

There is no clear way the utilities can make money using superconducting technology on a large scale. If you really look at the power industry, the electric power industry worldwide, electricity is cheap, and so one of my examples would be, supposing we came up with a superconductor that superconducted at room temperature at zero cost, would it still be attractive to tear down the 1200 mile DC voltage interchange from Seattle to Southern California just to save 6% or 7% in ohmic electricity loss? The answer to the utilities, although nobody verbalizes this, is that obviously there's no real strong economic incentive to do this in cost savings. This is one of the issues that plagues the general application of superconductivity: the electric power industry worldwide.

There are plenty of demonstration projects. They all work; the technology is pretty much mature now. The reason it's not being used, in my observation of the utility culture, is that there is no clear way to make a lot of money. And what would, in my vision, really encourage a large deployment of superconductivity, in particular in power transmission, would be a comeback of nuclear power.

SW: Tearing down a traditional transmission line costs money; however, these things naturally deteriorate and you have to replace them. Part of the reason for the implementation on the Munich grid that THEVA is trying out is because all of their transmission cables now are these old nitrogen pressurized cables that aren't being made anymore and can no longer be maintained. So that has become obsolete infrastructure that they have to replace anyway, which is maybe why they are open to trying something new. This could be an economic incentive.

PG: Near the end of my EPRI career, I served for a couple of years (2012-14) as an advisor to IASS-Potsdam, the Institute for Advanced Sustainability Studies, funded primarily by the German government. I had a pal who was one of the members of what we would call our DOE, but it's in Germany, and I would tease them; I'd say how come you are tearing down your nuclear plants? How many Germans have been killed by nuclear power accidents? Zero.

How many Germans are killed in automobile accidents every year on the Autobahn? About 800. So why don't you go to Frau Merkel - she has a PhD in chemistry - and say, why don't you expand the German nuclear power industry and then we can change all the autobahns to superconducting levitated trains and it will save 800 German lives a year at least? I mean I'm a wise ass American, so, the Germans just look at me and shake their heads, like, 'no, you don't know what we have to deal with'. The antagonism towards nuclear power is justifiable in terms of weapons control, which we can do separately from development as a source of electric power that's cheap and in certain aspects renewable, and certainly in terms of waste disposal is really pretty minimal; it's all a matter of politics and public perception.

SW: In a lot of your presentations, you were focused

▸ on using the same power distribution corridors that would exist in the natural gas industry to incorporate superconducting cables so you can essentially have energy produced at the site where it is collected and then distribute it at zero resistance across very long distances. Nuclear would make more sense; you could distribute it from a nuclear power generation source across wide geographic areas.

PG: Right, that's the continental super grid vision, described on my website at http://www.w2agz.com/PMG%20SuperGrid%20Home.htm. The bottom line is, how do utilities and governments make an attractive return on investment, both financially and societal, from that? That's a very challenging vis-à-vis preserving the present infrastructure and doing things the way it's being done now. When I was on sabbatical at the National University of Mexico, I looked a little bit into the issue of taking electricity generated by fracking on-site, rather than piping it around, and then distributing it by superconducting cables instead of pipelines. That makes technical sense, but I never saw a way, or at least I didn't observe the utility industry, either public or private, looking at this as a way to increase efficiency and save some money, and also environmental protection.

That's what makes the energy business rather unique compared to the computer industry. Improving computer technology makes money for a computer company as you go on in time; but you'll have to wait, in my opinion, for 16 months or until 2024 to see if quantum computers really turn out to be profitable.

There's a lot of hype in quantum computing. Think about quantum computing this way: it's sort of like a return to the era where you build a device that attacks one particular problem. For example, the ones that are currently particularly well known are quantum computers that are good at solving Ising type problems where you actually model in the hardware; the spin systems of a set of interacting spins, one way or another.

To me, quantum computing is a return to the era of analog computers, where you design a machine for a specific problem, where we have today the real revolution in computation that took place with Alan Turing and its implementation by von Neumann. I call them TvN machines, which in principle can solve any problem in physics, given enough time and enough power. Quantum computing is not general computing; however it's very successful at certain types of problems much more quickly.

SW: Problems that are not necessarily realistic or have much practical application?

PG: Well, I would say they are not capable of generalization in the same piece of hardware. D-Wave is very good at solving the Ising model. D-Wave kept everything secret by the way, they were very hard to deal with, I would talk to D-Wave people a lot at physical society meetings, and the answer would be, oh, we can't talk about that. So, I would recommend to the DOE, where I was on the advisory panel for superconductivity, why don't we just buy a D-Wave computer and take it apart and see what they have really done that works. I'm sure that it's a special purpose machine for one particular problem, not general purpose.

Now, it could take dozens of years to solve certain thermodynamic problems on a classical Turing machine, where if you build the registers around a specific physics model, like the Ising models that are my favorite example, then you can solve a problem rather rapidly on that quantum computer, in a matter of hours instead of years. But I think if you come up with something that is the salvation of mankind, you ought to be able to explain how to use it.

SW: So I'm not the only one who doesn't understand everything about quantum computers.

PG: Right. it's important because there are certain kinds of problems that can be solved a lot faster, but it's not general…

SW: Is commercial viability then limited because of limited applications that it has?

PG: Absolutely.

SW: So, going back to your thoughts on power distribution: if there isn't an economic incentive for utilities, the remaining incentives that I can imagine would have be regulatory. What if a government needs to implement environmental protection policies, especially ones that are more focused on climate, as seems to be the way the wind is blowing now? I know for example, speaking with THEVA about their infrastructure in Munich, it's because the EU now has a regulatory mission to reduce CO_2 emissions, so that

▸ could be one incentive. Are you saying the only way this technology could be adopted on a broader scale is with pressure from governments, because otherwise there's no economic incentive to utilities to actually do this?

PG: Yes, the control of carbon emissions is really important. Very critical, to me, in terms of the power aspect, is bringing back nuclear power, big time - it doesn't combust any fuels.

SW: My personal opinion is that nuclear is the best option we have for energy production in terms of cost effectiveness, and that it doesn't involve releasing CO_2 into the atmosphere in a big way. We've been interviewing other companies that are going towards fusion. Do you think that there is something to be done there? Do you think that small fusion reactors are viable and something that we could actually implement in utility grids in the near future?

PG: You are talking about the MIT project and the fallout from that? Because they are the largest progenitors and fans of fusion reactors.

SW: Yeah, Commonwealth Fusion Systems, the spinoff from MIT. And Tokomak Energy in the UK.

PG: Well, we'll see. If you mention nuclear power to the general public, the first thing they think of are bombs. I tease the fusion people at MIT when I see them at meetings - I say 'isn't there something called a hydrogen bomb? That uses fusion? Is that efficient?' And they just ignore me.

SW: One more thing I'd like to ask that I typically ask everyone is, looking back on your career and the experiences and successes you had, what advice would you give to people now that want to get involved in science and in industry? Obviously you come from a different time, and your career started in a way that by and large is no longer possible. That kind of story is special, but it's something from a time in U.S. development and the culture in this country that is no longer around. I can't imagine that sort of thing happening for someone now.

PG: This is some of the advice I give to my mentees at Clarkson: just learn as much physics and math as you can, and then spend your summers with Eastman Kodak or IBM or some company and look around at what problems are holding them back that they need to solve. But concentrate on the basic core elements and skills of engineering and science.

That's what I always like to do. My advice to students, the undergraduates I mentor at Clarkson, is, when you get a summer job at an industry, spend the first couple days going out on the factory floor and see what kinds of problems they need fixing. If you have a proper educational background, you will have the skills and talent to be able to attack those problems. Don't go into a closet; you have to get out there and look around and see what is going on the factory floor. That's what I pretty much did for my whole IBM career. I was rather different from my colleagues in the research division in that regard, but that's how I can best sum it up right now. Haul your ass out on the factory floor and see what problems need solving. Don't become a university professor.

SW: Or don't become one of those managers who are completely unfamiliar with what happens at every level of the company where they work.

PG: I often say, when I retired from IBM, I had probably four or five academic positions available to me. One, for example, was Dean of the Physics Department at UC Davis There were jobs like that, and I probably would have gone to Florida State University. At the last minute, I got a call from a friend of mine that worked at EPRI and we had collaborated when I was at IBM San Jose on certain projects that he was interested in. EPRI offered me a position as a science fellow, with a discretionary budget of five million dollars a year where I could hire university professors to work on projects that I wanted to see worked on, rather than go to a university and have to deal with students and faculty and all of the internal politics of what goes on in those institutions that I became very familiar with over the years. So, yeah, I really owe a big debt to EPRI for giving me this free money.

SW: Yeah, not having to write grants or beg for a budget.

PG: Exactly. So this is why I encourage my mentees to go into industry or government, I mean places like the NRL or national labs, and if you want to teach you can do that off the clock.

SW: Thank you for your comments. ■

Luminary

John Bardeen 1908-1997

John Bardeen was born in Madison, Wisconsin in 1908. His father was the first dean of the University of Madison Medical School. He attended primary and secondary school in Madison and in 1932 attended the University of Wisconsin.

In university, Bardeen joined a fraternity without enough money to pay the membership dues. However, with a lifelong passion for the game of billiards, he was able to finance his studies and fraternity dues through cash games in Madison pool halls and dive bars.

At school, Bardeen focused primarily on engineering, as he did not want to become an academic like his father, and he thought the job market for engineers looked promising. He completed his bachelor's degree in 1928 and his master's one year later.

In 1930, Bardeen moved to Pittsburgh to work as a geophysicist for the Gulf Research Labs, a subsidiary of the Gulf Oil Corporation, on developing methods for the interpretation of magnetic and gravitational surveys. After a few years, he lost interest in his work and applied for a mathematics graduate program at Princeton University.

At Princeton, Bardeen studied math and physics under Eugene Wigner. Before completing his program, he was offered a Junior Fellowship position by Harvard University, where he remained from 1935 to 1938, until he returned to Princeton to finish his PhD. In the same year, he went on a trip to Pittsburgh to visit some old friends and met Jane Maxell, whom he married soon after.

When the war broke out, Bardeen was sent to the Naval Ordnance Lab, where he worked on countermeasures to defend ships against magnetic mines and torpedoes.

After the war, Bardeen took a job at Bell Labs in Summit, New Jersey. This was where he met William Shockley and Walter Brattain. In 1947, the three of them went on to invent a point-contract transistor that achieved application. Although the transistor was primarily devised by Bardeen and Brattain, Shockley downplayed their roles and credited himself with the invention, which led to discord and the eventual end of their partnership.

The invention of the transistor was a major breakthrough for electronics, replacing vacuum tubes in televisions and radios, which were far bulkier and less energy efficient. The three would go on to be awarded to Nobel Prize in Physics in 1956.

Bardeen was not allowed to work on the transistor and focused his interests in superconductivity until leaving Bell Labs in 1951, when he took a position at the University of Illinois Urbana-Champaign as professor of electrical engineering. There, he established a program examining the flow of electrons in charge density waves (CDW) through metallic linear chain compounds and postulated that CDW electron transport was fundamentally quantum in nature.

In 1957, Bardeen teamed up with Leon Cooper and Robert Schrieffer to propose their famous theory of superconductivity, known today as BCS theory. They would be awarded the Nobel Prize for their efforts in 1972, making Bardeen the first-ever two-time Nobel laureate.

In 1997, Bardeen died of heart disease at the age of 82. He and his wife are buried in Madison, Wisconsin and are survived by three children and six grandchildren.

Bardeen is remembered for hosting large cookouts for his neighbors, where he would famously ask everyone whether they would like their bun toasted, as was his preference. Always modest and unassuming, many of his neighbors and friends were completely unaware of his scientific accomplishments. His biographer, Lillian Hoddeson, wrote that his genius was often overlooked by the public and media because of his ordinary appearance and behavior. ■

Patents

Vertical josephson junction superconducting device
IBM Corp.
September 22, 2020
U.S. Patent No. 10,784,432
In one embodiment, a chip surface base device structure is provided that comprises a substrate comprising crystalline silicon that is coupled with a first superconducting layer, wherein this first layer is coupled with a second substrate comprising crystalline silicon. In one implementation, the chip surface base device structure also comprises a vertical Josephson junction located in an etched region of the substrate, the vertical Josephson junction comprising a first superconducting layer, a tunnel barrier layer, and a top superconducting layer.

Graphene-based superconducting transistor
Raytheon BBN Technologies Corp.
September 22, 2020
U.S. Patent No. 10,784,433
In some embodiments, the transistor includes a first and a second superconducting source-drain, a graphene channel including at least a portion of a graphene sheet, and a conductive gate. The first and second superconducting source-drains, and the graphene channel together form a Josephson junction having a critical current. The channel forms a current path between the first and the second superconducting source-drains. The conductive gate is configured, upon application of a electric field across the conductive gate and the graphene channel by applying a voltage, to modify the critical current.

Current protection device with mutual reactor
Varian Semiconductor Equipment Associates, Inc.
September 22, 2020
U.S. Patent No. 10,784,673
Embodiments provide a current protection device with a mutual reactor including a first and a second winding. The current protection device is a subcomponent of a previously developed fault current limiter. The device protects the superconductor from potential damage. It may include a coil electrically connected in series with the first or second windings, an actuator mechanically coupled at an output of the coil, and an electrical interrupter electrically connected to the first and second windings, wherein the actuator is communicatively coupled with the electrical interrupter to actuate a moveable contact of a set of breaker contacts of the electrical interrupter. In some embodiments, the first and second windings are arranged in parallel to one another. In some embodiments, the coil is electrically coupled to an output of the first or second winding.

Superconducting computing system in a liquid hydrogen environment
Microsoft Technology Licensing, LLC
September 22, 2020
U.S. Patent No. 10,785,891
An example superconducting computing system includes a housing arranged inside a liquid hydrogen environment, where a lower pressure is maintained inside the housing than a pressure outside the housing. The superconducting computing system further includes a substrate, arranged inside the housing, having a surface, where a plurality of components attached to the surface is configured to provide at least one of a computing or a storage functionality, and the substrate further comprises a plurality of circuit traces for interconnecting at least a subset of the plurality of the components. The housing is configured such that each of the plurality of components is configured to operate at a first temperature, where the first temperature is below 4.2 K, despite the liquid hydrogen environment having a second temperature greater than 4.2 K.

Superconducting waveform synthesizer
U.S. Government, as represented by the Secretary of Commerce
October 6, 2020
U.S. Patent No. 10,797,684
A superconducting waveform synthesizer produces an arbitrary waveform and includes an encoder that produces a bitstream; a pattern generator that produces a current bias pulse from the bitstream; a Josephson junction that produces a quantized output pulse from the current bias pulse; and a converter that produces an arbitrary waveform from the quantized output pulse. A process for producing an arbitrary waveform includes producing a bitstream; producing a current bias pulse from the bitstream;

communicating the current bias pulse to a Josephson junction; producing, by the Josephson junction, a quantized output pulse from the current bias pulse; producing a quantized output pulse from the current bias pulse; and producing an arbitrary waveform from the quantized output pulse.

HTS wires having increased engineering current densities
American Superconductor Corp.
October 13, 2020
U.S. Patent No. 10,804,010
A superconductor wire having a first HTS layer with a first cap layer in direct contact with a first surface of the first HTS layer and a second cap layer in direct contact with a second surface of the first HTS layer. There is a first lamination layer affixed to the first cap layer and a stabilizer layer having a first surface affixed to the second cap layer. There is a second HTS layer and a third cap layer in direct contact with a first surface of the second HTS layer and a fourth cap layer in direct contact with a second surface of the second HTS layer. There is a second lamination layer affixed to the fourth cap layer. The second surface of the stabilizer layer is affixed to the third cap layer and there are first and second fillets disposed along a edge of the laminated superconductor.

Flexible superconducting lead assembly
GE Precision Healthcare LLC
October 13, 2020
U.S. Patent No. 10,804,017
A superconducting lead assembly comprising: a positive superconducting wire; a negative superconducting wire, wherein the positive superconducting wire is configured to conduct inflow current to a cryogenic apparatus and wherein the negative superconducting wire is configured to conduct outflow current away from the cryogenic apparatus; and an electrically insulating separator, wherein the positive superconducting wire and the negative superconducting wire are arranged proximately one another and on opposite sides of the electrically insulating separator for cancellation of electromagnetic forces attributable to current flowing simultaneously in opposite directions within the positive superconducting wire and the negative superconducting wire, and wherein a length of the superconducting lead assembly is flexible. In one embodiment the positive superconducting wire and the negative superconducting wire can include HTS material.

Partial insulation superconducting magnet
Massachusetts Institute of Technology
October 13, 2020
U.S. Patent No. 10,804,018
The magnet includes a coil with a non-insulated superconducting wire winding wound around a bobbin. The coil has a first wire layer, a second wire layer substantially surrounding the first layer, and a first layer of insulating material disposed between the first wire layer and the second wire layer. Each wire layer comprises a plurality of turns, and the first layer of insulating material substantially insulates the second wire layer from the first wire layer.

Backside coupling with superconducting partial TSV for transmon qubits
IBM Corp.
October 13, 2020
U.S. Patent No. 10,804,454
A capacitive coupling device (superconducting C-coupler) includes a trench formed through a substrate, from a backside of the substrate, reaching a depth in the substrate, substantially orthogonal to a plane of fabrication on a front side of the substrate, the depth being less than a thickness of the substrate. A superconducting material is deposited as a continuous conducting via layer in the trench with a space between surfaces of the via layer in the trench remaining accessible from the backside. A superconducting pad is formed on the front side, the superconducting pad coupling with a quantum logic circuit element fabricated on the front side. An extension of the via layer is formed on the backside. The extension couples to a quantum readout circuit element fabricated on the backside.

Joint portion of superconducting wires and method of joining superconducting wires
Hitachi, Ltd.
October 13, 2020
U.S. Patent No. 10,804,624
The present invention provides a joint portion of MgB2 superconducting wires having exceptional energization characteristics and high reliability. The joint portion of the superconducting wires has a space for filling Mg into a portion inside a container or pressurizing member, the portion not being adjacent to an MgB2 sintered body.

Superconducting combiner or separator of DC-currents and microwave signals
IBM Corp.
October 13, 2020
U.S. Patent No. 10,804,874
Techniques that facilitate a superconducting combiner or separator of DC-currents and microwave signals are provided. In one example, a device includes a direct current circuit and a microwave circuit. The direct current circuit comprises a bandstop circuit and provides transmission of a direct current signal. The microwave circuit provides transmission of a microwave signal. The microwave circuit and the direct current circuit that comprises the bandstop circuit are joined by a common circuit that provides transmission of the direct current and microwave signals.

Josephson transmission line for superconducting devices
Microsoft Technology Licensing, LLC
October 20, 2020
U.S. Patent No. 10,811,587
Josephson transmission lines (JTLs) for superconducting devices and related methods are provided. In one example, a device comprising a JTL for propagating quantum pulses in a first direction in response to an application of a clock signal having a plurality of phases is provided. The JTL may include a first inductive element coupled between a first and a second terminal, a first Josephson junction (JJ) coupled between the second terminal and a ground terminal, a second inductive element coupled between the second and a third terminal, and a second JJ coupled between the third terminal and the ground terminal. The second inductive element is configured to form an inductive loop, and the loop may be configured to operate in a mode such that a quantum pulse cannot travel in a second direction opposite from the first direction regardless of a phase of the clock signal.

Reel-to-reel exfoliation and processing of second generation superconductors
Brookhaven Technology Group, Inc.
October 20, 2020
U.S. Patent No. 10,811,589
The substrate and buffer layers, of either one-sided or two-sided superconducting tape, are separated from the YCBO layer(s) of the tape by a combined action of radiative or inductive heat and mechanical force via a reel-to-reel manufacturing process. The exfoliation process may also utilize an air blade(s) to facilitate the separation of the layers of the tape

Cryostat and associated maglev transport vehicle and system
Metrolab
October 27, 2020
U.S. Patent No. 10,814,730
A cryostat intended to be integrated into a maglev transport system, the cryostat comprising at least one superconductive element and a jacket inside which each superconductive element is placed. The cryostat is suitable for maintaining each superconductive element at the desired temperature and the jacket extending along a longitudinal axis. The length of each superconductive element along the longitudinal axis is comprised between 30% and 100% of the length of the jacket, and each superconductive element is a bulk element made of superconductor material.

Method and apparatus for evaluating superconducting tunnel junction detector noise versus bias voltage
XIA LLC
October 27, 2020
U.S. Patent No. 10,816,587
A technique for characterizing the noise behavior of a superconducting tunnel junction (STJ) detector as a function of its applied bias voltage by stepping the STJ's bias voltage across a predetermined range and, at each applied bias, making multiple measurements of the detector's current, calculating their mean and their standard deviation from their mean, and using this standard deviation as a measure of the STJ detector's noise at that applied bias. Because the method is readily executed under computer control, it is particularly useful when large numbers of STJ detectors require biasing, as in STJ detector arrays. In a preferred implementation, the STJ is measured under computer control by attaching it to a digital spectrometer comprising a digital x-ray processor (DXP) coupled to a preamplifier that can set the STJ's bias voltage using a digital-to-analog converter (DAC) controlled by the DXP.

Superconductor with improved flux pinning at low temperatures
The University of Houston System
October 27, 2020
U.S. Patent No. 10,818,416
A REBCO superconductor tape that can achieve a lift factor greater than or equal to approximately 3.0 or 4.0 in an approximately 3 T magnetic field applied perpendicular to a REBCO tape at approximately 30 K. In an embodiment, the REBCO superconductor tape can include a critical current density less than or equal to approximately 4.2 MA/cm2 at 77 K in the absence of an external magnetic field. In another embodiment, the REBCO superconductor tape can include a critical current density greater than or equal to approximately 12 MA/cm2 at approximately 30 K in a magnetic field of approximately 3 T having an orientation parallel to a c-axis.

Electronic circuit, oscillator, and calculating device
Kabushiki Kaisha Toshiba
NEC Corp.
October 27, 2020
U.S. Patent No. 10,819,281
According to one embodiment, an electronic circuit includes a first conductive component, a second conductive component, a first current path, and a second current path. The second conductive component is capacitively coupled to the first conductive component. The first current path of a superconductor includes a first and a second portion. The first portion is connected to the first conductive component. The second portion is connected to the second conductive component. The first current path includes N first Josephson junctions connected in series and provided between the first and second portions. The second current path of a superconductor includes a third and a fourth portion. The third portion is connected to the first conductive component. The fourth portion is connected to the second conductive component. The second current path includes a second Josephson junction connected in series and provided between the third and fourth portions.

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