New Minds Move Superconductivity into the Next 100 Years

Fermilab's Alex Romanenko recently unlocked secrets hidden beneath the mirror-smooth surface of niobium superconducting radiofrequency (SRF) cavities that may hold the key to the success of future linear colliders. Romanenko's discovery, which was based on research carried out as part of his doctoral thesis at Cornell University, has earned him "The Particle Accelerator Science and Technology Award" from the Nuclear Plasma and Science Society, part of Institute of Electrical and Electronic Engineers (IEEE). His award was one of many presented at the recent PAC'11 in New York City.

Romanenko's thesis work centered around one pressing question: why does a very modest final bake of niobium improve performance of cavities by as much as 30%, when the 120°C baking temperature is far below temperatures of metallurgical significance for the metal?

"A rather wide group of scientists had postulated that a 'pollution' layer exists near the oxide, and that the particular temperature was related to the diffusion of oxygen over distances important to RF superconductivity," said Lance Cooley, head of the Fermilab Technical Division's SRF materials group and new member of the CSA Board of Technical Directors. "Alex found that there was little if any evidence to support oxygen acting alone—something else had to contribute."

Even more puzzling was the fact that there was improvement in the perfection of the niobium grains, a phenomenon not expected to occur at these temperatures. To get to the bottom of the mystery, Romanenko applied very sensitive materials science probes to investigate the near-surface structure and contamination in niobium. Cooley says Romanenko's thesis uncovered evidence that hydrogen—in addition to oxygen—was the active element, and that the 120°C baking temp was ideal for providing hydrogen enough energy to escape from various defects in the niobium metal, which allowed those defects to heal and improve the grains.

The group is now focusing on the link between niobium hydride formation and losses in cavity performance.

"When cavities have a lot of hydrogen dissolved in the metal, e.g., due to polishing using concentrated acids, many precipitates of niobium hydride form during the cooldown to cryogenic temperature," Cooley explained. "Dissipation of RF power occurs at these precipitates, resulting in behavior called 'Q sickness', where the quality factor Q of the resonating cavity falls steeply as it is energized to produce accelerating electric field."

Normal protocol to combat "Q sickness" has been to bake the cavities at 800°C in high vacuum ovens, which de-gasses the hydrogen. But Romanenko's work suggests that either residual hydrogen can still be present or new hydrogen is introduced by final wet processing steps. While not in sufficient size or number to cause "Q sickness," the discovery implies that a small level of hydride precipitates could lead to losses at high accelerating fields. This problem must be met head-on by the Technical Division, since an accelerator like the ILC would require only the best performing cavities for its very high accelerating fields.

In a collaboration with the University of Western Ontario, Romanenko is applying helium atom recoil spectroscopy to explore the concentration of hydrogen just under the surface, a technique borrowed from silicon semiconductors.

In February 2011, ***R&D*** magazine reported that Danko van der Laan, a scientist working at NIST, had invented a method of making HTS cables that are thinner and more flexible than ever before. Van der Laan provided ***Cold Facts*** with more detail on his work and that of his colleagues at NIST as follows:

"The superconducting material that we used to make the cables is a high-temperature superconducting "coated conductor" that consists of a 50-micron-thick Hastelloy substrate, coated with ceramic buffer layers and a 1-micron-thick gadolinium-barium-copper-oxide (GBCO) superconducting film. The superconducting film is similar to yttrium-barium-copper-oxide (YBCO), but with the Y fully substituted by Gd. The superconductor was purchased from SuperPower Inc. in Schenectady, NY.

"[These materials'] tolerance to compressive strain is two-fold. First, the ceramic films can withstand relatively large compressive as well as tensile strain before mechanical damage occurs. This is mainly due to the very high level of grain alignment in almost all REBCO (rare-earth-barium-copper-oxide, with RE=Y, Gd, Dy, etc.) coated conductors. Applications are always designed in such a way that the conductor doesn't exceed the strain levels at which mechanical damage occurs. Second, the superconducting properties (critical current, magnetic flux pinning strength, etc.) change reversibly with strain, even before any mechanical damage occurs in the ceramic films. We are very close to proving that this reversible change is caused by the pressure dependence of the critical temperature of the superconductor. Earlier this year, we published a paper that proves this for bismuth-strontium-calcium-copper-oxide-2223 (Bi-2223) superconductors, and are close to providing the same evidence for REBCO coated conductors. The pressure dependence of the critical temperature (Tc) depends on the type of high-temperature superconductor. Some show a higher pressure dependence of Tc, which most likely causes a larger change in critical current with strain, while others show a relatively small change in Tc with pressure. We think, but haven't had a chance to measure this, that Tc of GBCO is less pressure dependent than that of YBCO, causing the "higher tolerance" to strain of GBCO, as demonstrated in the paper.

"I was aware that REBCO coated conductors are highly tolerable to strain, since I have studied many REBCO coated conductors under various strain conditions over the years. I came up with the idea that a coated conductor should tolerate a very tight bend around a former, thus allowing for a new compact cable design. The first challenge was to verify this. I therefore wrapped coated conductors around round formers with 1/8" (3.2 mm) diameter, and measured their performance.The concept was verified when the performance of the coated conductor wrapped around the former was similar to a straight sample that was put in the same strain state.

"The second challenge was to actually make high-current cables using this approach. After learning from our mistakes (by burning out several smaller cables), we came up with a method that worked. The next problem was to measure the performance of the cable at currents up to 3000A. This required a lot of low-noise current supplies that all had to work together to reach that level of current. To put it in perspective, as far as I know, the highest current in any conventional transmission line is about 3000A (this is one in Brazil), while most of them operate at currents below 1000A. Fortunately, Loren Goodrich from NIST had a lot of experience with low-noise, high current power supplies, having designed and constructed several power supplies from submarine batteries. His help really made the high-current cable tests successful."

Visit **www.cryogenicsociety.org/news** for more information about Van der Laan's work.