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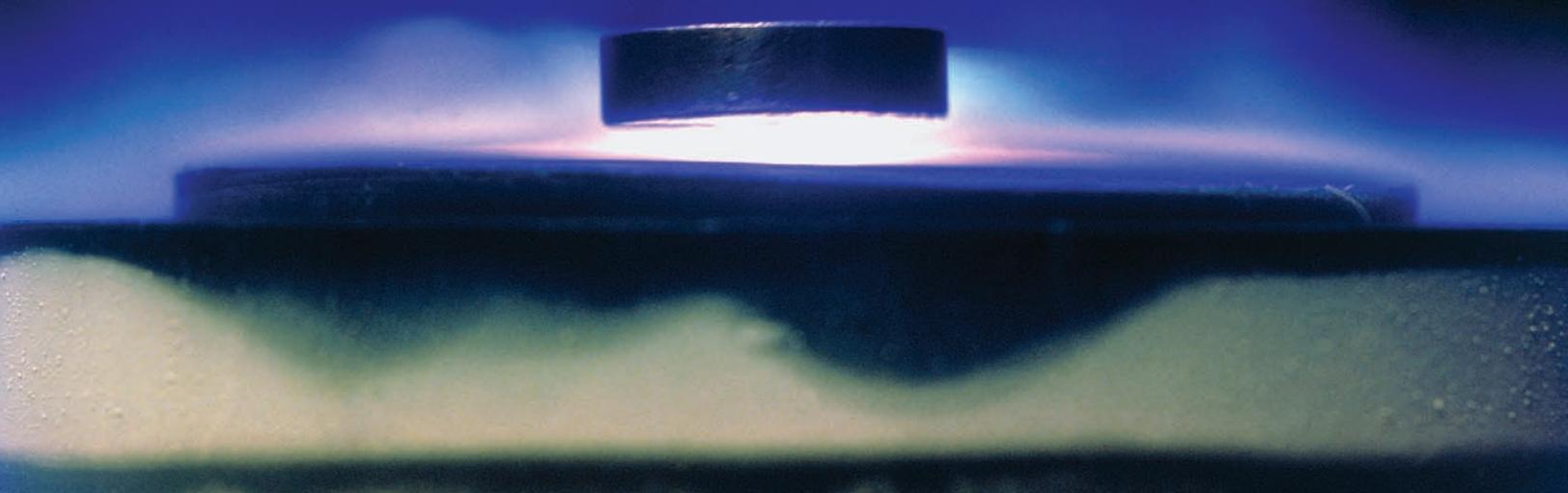
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SUPERCONDUCTIVITY

THE
FIRST

100

YEARS



Wiring the market

Firms have spent the last 25 years trying to create a market for high-temperature superconducting wires, but their widespread application may still be some years away. **Michael Banks** reports

“This will change the world,” was the first thought of Gregory Yurek, a metallurgist working at the Massachusetts Institute of Technology (MIT), when he heard about a major discovery in condensed-matter physics. It was 1986 and Georg Bednorz and Alex Müller, both working at the IBM Research Laboratory in Zurich, had just discovered that the electrical resistance of a material made from lanthanum, barium, copper and oxygen (LaBaCuO) fell abruptly to zero when cooled below a temperature of 35 K. The appearance of superconductivity – where a material can conduct electrons with zero resistance below the superconducting transition temperature – was only 12 K higher than the previous record of 23 K in Nb₃Ge, which was discovered in 1973. However, physicists knew that LaBaCuO was a major breakthrough because different elements in the material could be substituted for others, opening the door to potentially higher superconducting temperatures.

Within a year of Bednorz and Müller’s discovery, a new material based on yttrium, barium, copper and oxygen (YBa₂Cu₃O, also known as YBCO) became the first material to superconduct above the boiling point of liquid nitrogen at 77 K, with a superconducting transition temperature of 93 K. That was quickly followed in 1988 by a material containing bismuth, strontium, calcium, copper and oxygen (BSCCO) that superconducts at about 105 K. Results and new compounds were appearing thick and fast – there seemed no limit to what transition temperatures might be possible. With the dream of room-temperature superconductors alive, Bednorz and Müller’s discovery earned them the 1987 Nobel Prize for Physics.

It was all a revelation to Yurek, who immediately started to work on the chemical and physical properties of these materials. It was not just the understanding of these systems or the hunt for higher superconducting temperatures that fascinated him, but also how society could reap the rewards of the discovery for applications. Indeed, *TIME* magazine ran a whole issue in May 1987 devoted to the breakthrough: “Wiring the future:



Laying the ground work
The Holbrook Superconductor project at a substation in Long Island, New York, has been operating with some 160 km of superconducting cables since 2008.

the superconductivity revolution”. The dream then was of maglev “levitating” trains speeding through the countryside with the help of high-temperature superconducting magnets, as well as the promise of power distribution being revolutionized through the lossless transmission of electricity.

Keen to get in on the commercial possibilities, Yurek, together with his wife Carol and fellow MIT researcher John Vander Sande, formed American Superconductor (AMSC) in April 1987. They were buoyed by the fact that a new market for magnets in magnetic resonance imaging (MRI) was then slowly emerging that used superconducting wires from materials with lower transition temperatures, such as niobium tin (Nb₃Sn), which superconducts at 18.3 K.

Based in Devens, Massachusetts, the company now employs about 900 people. Yet in the 25 years since the discovery of high-temperature superconductors, the widespread application of them has somewhat failed to live up to its promise. Indeed, instead of producing hundreds of kilometres of cable for power grids all over the world as it had envisaged, AMSC has been steadily diversifying its business to other areas such as renewable energy. In the third quarter of 2010 – the latest available figures – barely \$2.1m of AMSC’s \$114.2m revenue came from its superconducting-wire business. The rest comes from AMSC’s “power systems” division, which provides wind-turbine designs and power electronics for wind turbines and the

power grid.

Yurek is, however, confident that the company’s fortunes and demand for superconducting cables is starting to take shape, or as he puts it “superconductors are now coming of age”. Indeed, there is some evidence to back up his claims. Last year South Korean power-cable manufacturer LS Cable placed the world’s largest order for some three million metres of wire from AMSC. LS Cable plans to use this wire to deploy approximately 25 km of superconductor power cables for the South Korean and global power-grid markets over the next several years.

However, other industry insiders are less sure that the time has come for high-temperature superconducting cables. “Utility companies are still to be convinced,” says Pradeep Hal-dar, who co-founded the US-based superconductor-wire manufacturer SuperPower, which was bought up by electronics giant Philips in 2006, and who now works at the University at Albany, State University of New York. “The promise is still there, but it is still a huge challenge to get it widespread in the industry.”

The optical fibre of wire

The first high-temperature superconductor material to be utilized in commercial wires was BSCCO-2223 (Bi₂Sr₂Ca₂Cu₃O_{10+x}) – known as a first-generation (1G) wire – that AMSC brought out in 1995. These superconductor wires are made by packing ceramic powders of BSCCO into silver tubes. The packed powder is extracted and rolled into a flat tape, which is heated to make it suitable for winding cables or coils for transformers, magnets, motors and generators.

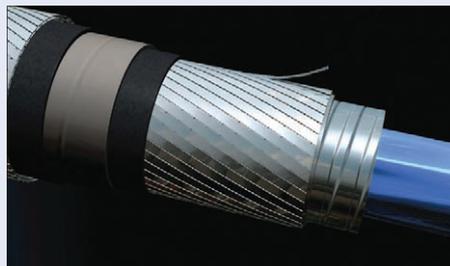
Typical BSCCO tapes are 4 mm wide and 0.2 mm thick, and can support a current at 77 K of 200 A, giving a critical current density of about 10⁴ A cm⁻². To make a superconducting cable, the tapes are typically wrapped around a copper core, surrounding which are various levels of electrical shielding. The cables also have thermal insulation for the liquid nitrogen, which is used to cool the tape down to 77 K.

One big success of this 1G wire came in 2008, when it was used in a transmission-voltage superconducting power cable that operated at industry standards for the first time in a grid setting. Funded by the US Department of Energy, the Holbrook Superconductor project involved about 600 m of underground cable containing about 160 km of AMSC’s BSCCO

Superconductors head into the niche

While wire manufacturers wait for utility companies to show more interest in high-temperature superconducting cables, second-generation (2G) wires are finding some applications in generators and motors. A generator's weight can be reduced significantly – by a half or so – with superconductor wires as there is no need for a heavy iron core in the generator. “But when designing a motor or generator with superconducting wires, you have to throw away the book and basically start from scratch,” says Gregory Yurek of American Superconductor (AMSC). “People in the industry say ‘wow that’s fantastic, but I don’t know how to change my business.’”

Yurek says this is why AMSC has decided to start building and selling its own generator and motors that take advantage of superconducting wires. “Sometimes you can’t depend on other companies



and have to take it forward yourself,” he says. One example is in wind turbines, where superconducting cables can be used in the generator to make it more efficient than conventional generators. There is also some interest from the US Navy in using generators made with superconducting wires so that the size and weight of vessels can be reduced. In fact, AMSC

has successfully tested the world’s first 36.5 MW high-temperature superconducting ship-propulsion motor, which has been built at the US Navy’s Integrated Power System Land-Based Test Site in Philadelphia.

Although the industry that AMSC was created to pioneer has yet to fully take off, optimism abounds. “If you look back in history, you would have said that in the 1950s superconductivity looked like a failure, but then magnetic resonance imaging came along and created a billion-dollar industry,” says Pradeep Haldar, who co-founded the US-based superconductor-wire manufacturer SuperPower and now works at the University of Albany, State University of New York. “In my view, we will find a silver-bullet application for high-temperature superconductors, the question we do not know at the moment is what it will be.”

wire, installed at a Long Island substation in New York. The superconducting wire has been successfully operating in the grid since April 2008. Although the demonstration succeeded, the problem with BSCCO wire is that making it requires a lot of silver, which is expensive, and means 1G wires are unlikely to ever be cost-effective when compared with copper.

While other wire manufacturers, such as Japan’s Sumitomo, are still using BSCCO wires, AMSC and SuperPower have already brought out a second-generation (2G) wire, which is based on YBCO. Although YBCO has a lower superconducting transition temperature than BSCCO, it could potentially deliver much higher current densities of about 10^6 A cm^{-2} – more than 100 times the current density of copper wires – and outperforms BSCCO in high magnetic fields. “We think that it may be possible for YBCO wires to have a much higher current density, reaching about 10^7 A cm^{-2} ,” says Venkat Selvamanickam, SuperPower’s chief technology advisor who is based at the University of Houston, Texas.

Making YBCO involves depositing layers of the superconductor onto a substrate consisting mostly of nickel rather than silver. YBCO wires are about 4–12 mm wide and 0.1 mm thick, and are 1% YBCO with the rest being the nickel, copper and a little silver. Selvamanickam says that SuperPower’s technique can produce wire more than 1 km in length.

As for AMSC’s 2G wire, which goes under the name “Amperium”, it can conduct more than 100 times the electrical current of copper wire of the same dimensions. It now accounts for 85% of all wires sold to industry, and the company has more than 150 pa-

tents on the wire. Yurek calls Amperium the “optical fibre of wire” because just as high-capacity optical fibres have revolutionized the telecoms industry, so superconducting wires, he thinks, will revolutionize the electric power industry.

That may sound optimistic, but wires based on YBCO are starting to be used. AMSC, for example, is involved in the \$1bn Tres Amigas SuperStation, which is located in Clovis, New Mexico, and is expected to be in operation by 2014. The station will connect the US’s three power grids – the Western, Eastern and Texas interconnections – to increase the reliability of the grid and to enable a faster adoption of renewable energy. The grids will be linked together via three superconducting high-voltage direct-current power transmission lines, which allow for much better control of energy and are much more efficient than conventional cables.

There is also a \$39m project called “Hydra”. Initially proposed in 2007, it was put on hold following the global economic downturn, but is now, according to Yurek, “back on the table”. Partially funded by the US Department of Homeland Security, it will deploy 2G wire into the grid in lower Manhattan to protect substations from fault currents – power surges that could damage grid connections. “I think what you are likely to see over the next 10 or 20 years is utilities installing more demonstration cables here and there, but not on a huge scale,” says Haldar.

A superconductivity revolution?

So why have utility companies around the world not been falling over themselves to install superconducting wires? “The issue with Long Island

and the like is that, although they show that superconducting wires can work, it is not at all a market demonstration,” says Haldar. “Utility companies need something to be tested to work on the scale of many years, maybe up to 30 years, to show that the cables can survive.”

Yurek also blames the “notoriously slow” power industry – sentiments that are reiterated by Trudy Lehner, director of marketing and government affairs at SuperPower. “We have a saying in the industry that the utility companies like to be first to be second,” he says. Another barrier is the price of uprooting parts of a grid to install new cable. Moreover, the current global economic downturn has dissuaded many firms from investing in new infrastructure. “Utility companies have basically told us that they cannot invest at this time, so they have put it back on the shelf,” says Yurek.

Although the cost of YBCO wires is coming down all the time, Selvamanickam says that superconducting cables are still about a “factor of five” times more expensive than standard copper cable, mostly because of the need for coolant systems. However, Haldar thinks that the cost of coolant is a red herring. “In addition to cost, training a whole new set of engineers to work with it, entering an already mature industry and turning it on its head is very hard to do,” he says.

Yet Yurek is expecting a number of “meaningful orders” from China in the coming months and is confident that the US and Europe will eventually begin to catch up with Asia. “As an American who has put a lot of blood, sweat and tears into this, it is a pity [the US is not leading],” says Yurek. “But I am confident that will change at some point.”

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