HIGH-TEMPERATURE SUPERCONDUCTOR WIRE

American Superconductor Corp. has won the 2007 Engineering Materials Achievement Award for its second-generation high-temperature superconductor wire.

Alex Malozemoff
American Superconductor Corporation
Westborough, Massachusetts

The initial development in 1986 of high-temperature superconducting materials triggered an overwhelming global response. Universities, private and government labs, and scores of corporations launched efforts to capitalize on these remarkable materials.

In the years leading up to the discovery, another game-changing technology was being widely deployed: fiber-optic cables. Because these cables vastly increased voice and data transmission capacity and speed, they served as an exhilarating preview of what commercialized HTS wires might do for power transmission. Yet these HTS materials were inherently brittle ceramics that were extremely challenging to fabricate into wire. The foremost challenge was how to incorporate them into a flexible wire product that could be leveraged in a wide variety of high-power applications.

Bending the unbendable

Between AMSC's founding in 1987 and the mid-1990s, the company devoted a great deal of effort to changing these brittle ceramics into flexible engineering materials. The company emerged as a pioneer in this regard, devising a manufacturing method to shape HTS wire via deformation technologies based on the metal wire industry.

In this approach, a silver tube is packed with an oxide precursor powder and sealed. The tube is then "deformed" into the shape of a wire by a variety of techniques, including wire-drawing, multi-filament bundling, and rolling. Finally, the wire is heat treated to transform the precursor powder into a high-temperature superconductor.

The resulting composite structure consists of many fine superconductor filaments embedded in a silver matrix. This patented process allowed AMSC to "bend the unbendable" and create wires that outperformed traditional conductors such as aluminum and copper. These wires continue to be applied in cables, motors, generators, and transformers. However, the manufacturing process proved too expensive for broad commercial acceptance, and a lower-cost method had to be developed.

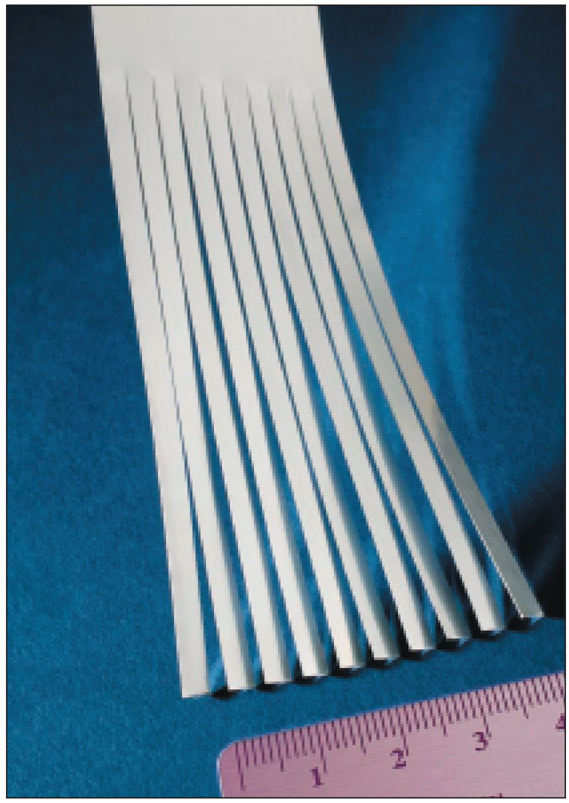

Fig. 1 — To make 344 superconductors, 4-cm wide strips are slit and laminated into many industry-standard ribbon-shaped wires that are 4.4 mm wide.

Superconducting ribbons

In the late 1990s, AMSC began developing a second generation (2G) HTS wire called 344 superconductors, the winner of this year's Engineering Materials Achievement Award. These 344 superconductors are ribbon-shaped wires that are

The Engineering Materials Achievement Award

Established in 1969 by ASM International, this award recognizes an outstanding achievement in materials or materials systems relating to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product. The recipient may be an individual, a team, or entire organization. The purpose of the award is to seek out and recognize outstanding developments in the application of materials in products that benefit industry, the consumer, and society as a whole. Visit www.asminternational.org for details.

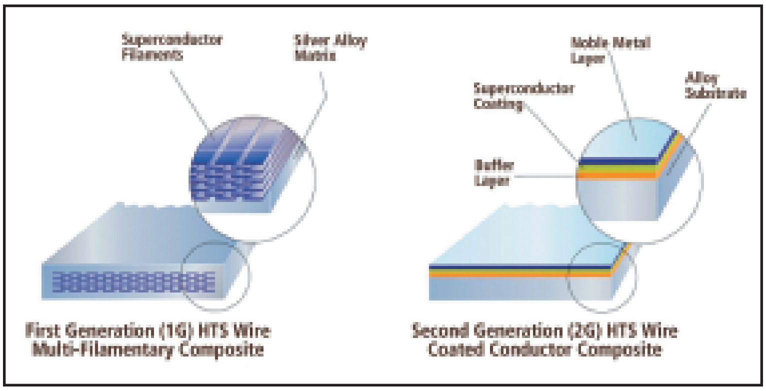

Fig. 2 — AMSC's first generation HTS wire (shown on the left) has been sold to customers in more than 20 countries around the globe, making it the industry workhorse for past application development programs. The graphic on the right shows the basic architecture for AMSC's second generation superconductor wire, which the company has branded as 344 superconductors.

4.4 mm wide. The core of 344 superconductors consists of multiple thin ceramic coatings of several materials, including a thin coating of HTS material, on a nickel-base alloy. The base metal and ceramic layers are engineered to provide a template for the HTS layer to grow in the proper orientation along the entire wire. Proper orientation of the HTS grains is necessary for the wire to transmit large amounts of current over long lengths. In addition, the ceramic layers are designed to maintain chemical compatibility with the base metal.

Figure 2 shows AMSC's wire manufacturing technology. Similar to the production of motion picture film (in which celluloid strips are coated with a liquid emulsion), it involves a low-cost, continuous reel-to-reel technology in which strips of superconductor material are produced in a high-speed deposition process. The resulting 4-cm wide strips are slit into many industry-standard 0.44-centimeter-wide, tape-shaped wires. These are laminated on both sides with copper or stainless-steel to provide strength, durability, and certain electrical characteristics. The three-ply, 4.4 millimeter-wide second generation HTS wires are therefore called 344 superconductors.

This reel-to-reel wide strip process enabled AMSC to reduce its wire manufacturing costs by as much as 80% compared with its first generation wire. This cost reduction will allow power systems made with 344 superconductors to compete head-to-head with copper-based systems within the next few years.

HTS applications

The promise of HTS is far-reaching, and development efforts are underway today for a vast array of applications for end markets such as ship propulsion motors and generators, magnetically levitated trains, and wind power. However, demand in the near term is expected to be driven primarily by utility applications as several promising products enter the commercial market.

• **Power cables:** After a decade of development, the summer of 2006 saw the first two HTS cables go into the U.S. grid. In Columbus, Ohio, American Electric Power energized a distribution voltage HTS system in its grid. The cable, powered by AMSC's first generation wire, carries a 13.2 kV load and has now been serving residential and industrial customers in Columbus flawlessly for more than a year. The same can be said for a National Grid distribution-voltage system in Albany, New York. This system was energized in August 2006 with first-generation HTS wire from Japan's Sumitomo Electric.

Momentum will continue to build later in 2007 when another HTS power cable system is energized by Long Island Power Authority. This will be the first in-grid deployment of a transmission-voltage HTS cable system. Powered by first-generation AMSC wire, it is designed to transmit more than 500 megawatts of power, enough electricity for 300,000 homes.

In June, the U.S. Department of Energy announced the selection of two new HTS cable projects in which second-generation HTS wire will help accelerate much-needed modernization of our nation's electricity grid. A new HTS cable in the Entergy system will solve a real-world electrical load problem near downtown New Orleans. Also, a single-phase prototype cable will be deployed in the Long Island Power Authority power grid, marking the first in-grid deployment of a system powered by AMSC's 344 superconductors.

• **Fault current limiters***:* Power surges — or fault currents, as they are known in the utility industry — are a growing issue for today's grids. These power surges are increasing in frequency and magnitude as more power is transmitted to meet the demands of today's digital economy, and they are reaching the limits of available circuit-breaker technology.

AMSC's 344 superconductors are able to switch rapidly from a superconductor to a resistive state when the electrical current passing through them exceeds a critical value. This prevents faults from passing along a network and protects vital electrical equipment. This unique capability enabled the development of a new utility product known as a "fault current limiter." The addressable market for fault current limiters has been estimated in the billions of dollars. In early 2007, both Siemens and Hyundai Heavy Industries announced the successful demonstration of stand-alone fault current limiters based on AMSC's 344 superconductors.

• **Secure Super Grids***:* Consolidated Edison Inc., one of the nation's largest investor-owned energy companies, recently teamed with AMSC to deploy a new HTS power grid technology in Manhattan under a contract with the U.S. Department of Homeland Security. AMSC's Secure Super Grids technology is based on customized HTS power cables with 344 superconductors and ancillary controls to deliver more power through the grid while also suppressing fault currents — a compelling product integration that signals a tipping point for HTS commercialization.

Secure Super Grids will allow utilities to insert new links in their networks to maintain power in critical centers of commerce under a variety of challenging conditions, including severe weather, accidents, or attacks. Testing of a first system is targeted for completion by the end of 2008. The project's second phase will focus on deploying the Secure Super Grids solution in Manhattan in early 2010, meeting Con Edison's construction schedule.

From lab to market

By the end of 2007, AMSC will initiate volume production of 344 superconductors on a pilot line equipped with full-scale manufacturing equipment. This will be a landmark event for the company and a notable milestone for the industry. Studies of the commercialization of other advanced materials like this next-generation wire show that, on average, about 20 years are required to migrate new materials from the laboratory to the market. Having been founded in 1987, AMSC appears right on schedule to cross the commercial threshold with 344 superconductors.

For more information: Alex Malozemoff is Executive Vice President and Chief Technical Officer, American Superconductor, Two Technology Drive, Westborough, MA 01581; email: amalozemoff@amsc.com; tel: 508/836-4200; fax: 508/836-4248; www.amsuper.com.

Fig. 3 — High temperature superconductor wire allows power cables to be manufactured that can support up to ten times the capacity of conventional cables based on copper wire. They support load growth, enable cost-effective controllability of power over a meshed grid, and can be implemented with low environmental impact. Liquid nitrogen, the dielectric and coolant of choice to maintain HTS wire at its operating temperature, is inexpensive, abundant, and environmentally safe — eliminating the oil currently used in many conventional power cables.