EDITORIAL

Superconductivity Revisited

In 1987 the great excitement about high-temperature superconductivity was accompanied by a hype about applications. In hundreds of laboratories specimens of $YBa_2Cu_3O_{7-\delta}$ were synthesized and their superconductivity was confirmed. However, the solids were brittle and performed poorly in the presence of external magnetic fields. Practical applications seemed far distant. But since then substantial progress has quietly been made. Additional superconductors have been discovered. Experts state that advances in synthesis and processing of high-temperature superconductors (HTSCs) now make it justifiable to consider development of prototype devices and products.

Since 1987 thousands of compounds have been prepared and examined. More than 75 of these were found to be superconducting at temperatures greater than 21 K. These 75 belong to three general compound types: cuprates, bismuthates, and fullerites. Of these three the cuprates are of special interest.

The limiting high temperatures for superconductivity (T_c) are important because of costs of refrigeration. A T_c of at least 77 K (boiling point of nitrogen) is desirable. Of the many cuprates having a T_c greater than 77 K, four have drawn the most attention. These are $YBa_2Cu_3O_{7-\delta}$, $Bi_2Sr_2Ca_2Cu_3O_y$, $TlBa_2Ca_2Cu_3O_x$, and $Tl_2Ba_2Ca_2Cu_3O_y$ (T_c is 125 K).

The T_c is only one factor in determining potential usefulness. Maximum current-carrying capacity [J_c in amperes per centimeter squared (A/cm^2)] is important. The J_c at a given temperature cannot be exceeded; otherwise the material ceases to superconduct. A third factor is the behavior of a superconductor in a magnetic field. The crystalline structures of the various HTSCs respond differently to magnetic fields. Some J_c's are greatly diminished by fields of 1 tesla.

The current-carrying capacity of the various superconductors is closely related to the way in which they are processed. In turn, the configuration employed is dependent on the specific application.* For example, thin films have potential for use in SQUIDs (superconducting quantum interference devices), Josephson junctions, and infrared sensors. The thin films (less than 3000 angstroms thick) are prepared by epitaxial growth on single-crystal substrates such as $LaAlO_3$. The preparation methods include sputtering, molecular beam epitaxy, and chemical vapor deposition followed by heat treatment in an oxygen atmosphere. The J_c for highly oriented single-crystal thin films of $YBa_2Cu_3O_{7-\delta}$ has been found to be 5×10^6 A/cm^2 at 77 K and 5×10^7 A/cm^2 at 4.2 K.

Wires and tapes made from some of the cuprates are approaching the electrical and mechanical requirements for use in electromagnets and for prototype superconducting motors, generators, and power transmission cables.† To be commercially useful, wires or ribbons must be capable of sustaining a J_c of at least 10^4 A/cm^2. They must possess this J_c while being exposed to a magnetic field that is either self-generated or imposed. Power transmission cables would operate in a low magnetic field. Superconductors in motors or generators would be exposed to self-generated fields of at least several tesla.

The required wires or ribbons are made by a process in which tubes of silver are filled with fine-grained $Bi_2Sr_2Ca_2Cu_3O_y$ and minor constituents. The tubes are drawn, heat-treated, and redrawn and ultimately treated with oxygen. (At high temperatures oxygen diffuses through the silver.) The minor constituents help promote a desirable crystal growth. Wire samples 100 meters or longer have been fabricated. Tests have shown that these will find application in producing very high magnetic fields at 4.2 K. The present technology uses NbTi and Nb_3Sn. But the new superconductor wire is superior at fields greater than 15 tesla at low temperatures. Recently samples of HTSC wire have shown a J_c of 48,000 A/cm^2 (at 20.2 K and 20 tesla) versus 10,000 A/cm^2 for Nb_3Sn wire.

Scanning some of the recent relevant literature leads to the conclusion that progress is being made toward many applications. Scientists and engineers in the United States and elsewhere are accumulating the necessary knowledge and deep intuitive feeling for managing the behavior of tricky but reproducible substances. One is inclined to have faith in experts who have stated that only further incremental improvement is needed to achieve commercial equipment containing high-performance HTSCs by the end of the decade.

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*For a review, see S. Jin and J. E. Graebner, *Mater. Sci. Eng.* **B7**, 243 (1991). †"Energy Applications of High-Temperature Superconductors: A Progress Report" (Electric Power Research Institute, Pleasant Hill, CA, 1992).