

SCIENCE

Publisher: Richard S. Nicholson
Editor: Daniel E. Koshland, Jr.
Deputy Editor: Ellis Rubinstein
Managing Editor: Monica M. Bradford
Deputy Editors: Philip H. Abelson (*Engineering and Applied Sciences*); John I. Brauman (*Physical Sciences*); Thomas R. Cech (*Biological Sciences*)

Editorial Staff

Assistant Managing Editor: Dawn Bennett
Senior Editors: Eleanore Butz, R. Brooks Hanson, Barbara Jasny, Katrina L. Kelner, Linda J. Miller, Phillip D. Szurmi, David F. Voss
Associate Editors: Gilbert J. Chin, Pamela J. Hines, Paula A. Kiberstis, Suki Parks, L. Bryan Ray
Letters: Christine Gilbert, *Editor*; Steven S. Lapham
Book Reviews: Katherine Livingston, *Editor*
Contributing Editor: Lawrence I. Grossman
Chief Production Editor: Ellen E. Murphy
Editing Department: Lois Schmitt, *Senior Copy Editor*; Douglas B. Casey, Valerie Jablow, Harry Jach
Copy Desk: Joi S. Granger, Beverly Shields, Kirsten L. Wall
Editorial Support: Sherryf Farmer, *Supervisor*; Carolyn Kyle, Michele Listisard, Diane Long, Patricia M. Moore, Melissa Quackenbos, Kameaka Williams
Administrative Support: Sylvia Kihara, Jeanette Prastein

News Staff

Managing News Editor: Colin Norman
Deputy News Editors: Tim Appenzeller, John M. Benditt, Jean Marx
News and Comment/Research News: Ivan Amato, Faye Flam, Troy Gately (copy), Ann Gibbons, Constance Holden, Richard A. Kerr, Eliot Marshall, Leslie Roberts, Richard Stone, Dawn Levy (intern)
Bureaus: Peter Aldhous (London), Marcia Barinaga (West Coast), John Travis (Northeast), Anne Simon Moffat (Midwest)
Contributing Correspondents: Joseph Alper, Barry A. Cipra, Jon Cohen, Robert Crease, Elizabeth Culotta, Robert Pool, M. Mitchell Waldrop
Administrative Support: Fannie Groom

Art & Production Staff

Production: James Landry, *Director*; Wendy K. Shank, *Manager*; Catherine S. Siskos, *Assistant Manager*; Scherraine Mack, *Associate*; Linda C. Owens, *Macintosh Operator*
Art: Amy Decker Henry, *Director*; C. Faber Smith, *Associate Director*; Diana DeFrancesco, *Technical Illustrator*; Holly Bishop, *Graphics Assistant*
Administrative Support: Leslie Blizard

Associate Publisher: Beth Rosner
Circulation Director: Michael Spinella
See Letters page for additional Advertising and Circulation Staff

Science Editorial Board

Charles J. Arntzen	John J. Hopfield
Elizabeth E. Bailey	F. Clark Howell
David Baltimore	Paul A. Marks
William F. Brinkman	Yasutomi Nishizuka
E. Margaret Burbidge	Helen M. Ranney
Pierre-Gilles de Gennes	Robert M. Solow
Joseph L. Goldstein	Edward C. Stone
Mary L. Good	James D. Watson
Harry B. Gray	

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 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 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 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_x$, and $\text{Tl}_7\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ (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 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ has been found to be $5 \times 10^6 \text{ A}/\text{cm}^2$ at 77 K and $5 \times 10^7 \text{ A}/\text{cm}^2$ 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 $10^4 \text{ A}/\text{cm}^2$. 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 $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ 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 $48,000 \text{ A}/\text{cm}^2$ (at 20.2 K and 20 tesla) versus $10,000 \text{ A}/\text{cm}^2$ 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.

Philip H. Abelson

*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).