



# RARE-EARTH INFORMATION CENTER NEWS

INSTITUTE FOR PHYSICAL RESEARCH AND TECHNOLOGY  
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## RE—BYC

### 1787—1987

Discovery of Nd-Fe-B Magnets

by Arthur L. Robinson\*

Center for X-Ray Optics

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When it was discovered in the mid 1960s by Karl Strnat and his co-workers at the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, and the General Electric R & D Center, Schenectady, New York, SmCo<sub>5</sub> was the most powerful magnet material known with an energy product (BH<sub>m</sub>) of 143 kJ/m<sup>3</sup>. If Co had been cheaper and if there had been a reliable source of Co, the development of Nd-Fe-B magnets might not have happened or at least been delayed. The 1978 shortage of Co due to fighting in Zaire precipitated a search for Co-free permanent magnets. Fe, like Co, has a large magnetic moment but neither have high magnetocrystalline anisotropy. Metallurgists add rare earths to transition metals because the compounds they form sometimes have structures with the required high anisotropy energies. The trick is to achieve this without losing the high magnetization through dilution of the magnetic moment. The trouble with Fe is that, unlike Co, it does not form many compounds with the rare earths and they have unimpressive magnetic properties. After Arthur Clark's (Naval Surface Weapons Center) discovery in 1973 that RFe<sub>2</sub> compounds (R = Tb, Dy, or Sm) had improved coercivities if they were prepared in the amorphous state, then annealed, scientists concentrated on finding amorphous mate-

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\*Condensed from "Powerful New Material Found," Robinson, A. L. (Research News Section), *Science*, 223, 920-2, 2 March 1984. Copyright 1984 by the AAAS.

## Ceramic Superconductors

"Ceramic Superconductors" is the title of volume 2, number 3B of *Advanced Ceramic Materials*. This special supplementary issue contains 49 papers that are divided into sections on phase equilibria, processing and fabrication, properties and characterization, theory, and history. As usual, in this fast moving field, many of the references are to papers that have been submitted or are in press.

This volume is free to current subscribers. Others may obtain the 735-page special issue published by the American Ceramic Society for U.S.\$48.00. To order this special issue write American Ceramic Society, Book Sales Department, 757 Brookedge Plaza Drive, Westerville, Ohio 43081-2821, U.S.A.

rials that could be annealed.

In the early 1980s, Norman Koon and Badri Das (Naval Research Laboratory), aware that boron enhances the likelihood of rapidly cooled materials being amorphous, looked at the Tb-La-Fe-B system. They found that as they annealed these amorphous alloys at successively higher temperatures, the coercivity rose sharply, then decreased.

During the same 1980 to 1982 period, John Croat's group at the General Motors Research Laboratories in Warren, Michigan, prepared a series of melt-spun Nd-Fe specimens at different wheel speeds. As expected the coercivity of the unannealed specimens increased dramatically with spinning speed, then unexpectedly dropped off. Croat's interpretation was that a magnetically active phase did not form at low speeds, but at higher speeds one did form and the coercivity rose. At still higher speeds the grains became so small that their

(Continued on page 4)

## IEEE Award

Dr. Andrew H. Bobeck was awarded the Magnetics Society 1987 Achievement Award for exceptional accomplishments and contributions to the field of magnetics. The



award by the Institute of Electrical and Electronics Engineers was presented in April at the 1987 Intermag Conference in Tokyo, Japan.

Dr. Bobeck joined the technical staff of AT&T Bell Laboratories in 1949 and specialized in the development of magnetic components. His interest in magnetic logic and storage led to the magnetic bubble concept of which he is co-inventor and author of the first technical paper. Perhaps his most significant discovery was that garnet materials can be prepared with a growth-induced axial anisotropy, an observation that led to the epitaxial garnet films in general use today.

Seasons  
Greetings



## CONFERENCE CALENDAR

- International Conference on High-Temperature Superconductors and Materials and Mechanisms of Superconductivity (HTSC-M<sup>2</sup>S)  
Interlaken, Switzerland  
February 29-March 4, 1988  
*RIC News*, XXII, [2] 2 (1987)
- 1st International School on Excited States of Transition Elements  
Ksiaz Castle, Wroclaw, Poland  
June 20-25, 1988  
*RIC News*, XXII, [3] 2 (1987)
- 6th International Conference on Crystal Field Effects and Heavy Fermion Physics  
Frankfurt, West Germany  
July 18-21, 1988  
*RIC News*, XXII, [2] 2 (1987)
- 18th Rare Earth Research Conference (RERC)  
Interlaken, Lake Geneva, Wisconsin, U.S.A.  
September 11-15, 1988  
*RIC News*, XXII, [3] 3 (1987)
- \*1st International Conference on Metallurgy and Materials of Tungsten, Titanium, Rare Earths, and Antimony (W-Ti-RE-Sb '88)  
Changsha, People's Republic of China  
November 5-8, 1988  
This Issue
- TMS-AIME Rare Earth Symposium  
Las Vegas, Nevada, U.S.A.  
February 27-March 3, 1989  
*RIC News*, XXII, [2] 2 (1987)

### High T<sub>c</sub> Superconductors

There are so many conferences on this subject that we have made no attempt to list them individually in the *RIC News*. For information on these meetings you may contact the RIC or better yet, check the current issues of *High T<sub>c</sub> Update*. To receive this publication, write Ellen Feinberg, 12 Physics, Ames Laboratory, Iowa State University, Ames, Iowa 50011, U.S.A.

\*New Listing

## PROCEEDINGS

### 9th Magnet Workshop

The *Proceedings of the Ninth International Workshop on Rare-earth Magnets and Their Applications* (Vol. I) and *Fifth International Symposium on Magnetic Anisotropy and Coercivity in Rare Earth-Transition Metal Alloys* (Vol. II) held from August 31 through September 3, 1987, in Bad Soden, West Germany, are now available. In Europe orders should be sent to the publisher: Dr. R.

(Continued in next column)

## The Price of Truth

The RIC has recently acquired an interesting 132-page book written by Dr. Dmitri Trifonov, a Soviet chemist working on the history of chemistry. First published in Russian in 1977, *The Price of Truth, The Story of Rare-Earth Elements* was published in an English version in 1984 by Mir Publishers of Moscow, U.S.S.R., and is available from Imported Publications Incorporated, 320 West Ohio Street, Chicago, Illinois 60610, U.S.A. The cost of the paperback English version is only U.S.\$3.95 plus \$1.00 for postage and handling.

The story starts with the discovery of ytterbite in 1787 and weaves an intriguing tale of the discoveries of the individual rare earths, their properties and uses, and ends with speculation on the actinides and their similarities and differences. The book is well illustrated with many illustrations printed using several colors.

(Continued from previous column)

Poerschke, Deutsche Physikalische Gesellschaft, Hauptstrasse 5, D-5340 Bad Honnef 1, West Germany. Elsewhere, order from Dr. Karl Strnat, Magnetics Laboratory, KL-365, University of Dayton, 300 College Park, Dayton, Ohio 45469, U.S.A. The cost in Europe is DM 120 for Vol. I and DM 60 for Vol. II. Elsewhere, the price is U.S.\$65.00 for Vol. I and U.S.\$35.00 for Vol. II plus a \$5.00 handling/shipping charge or \$12.00 for air mail per volume.

Volume I, the Workshop, has 756 pages and is composed of nine sections. The first four sections are devoted to magnet circuit design and electromechanical, magnet guidance, and magnetomechanical applications. The last five sessions are devoted to raw materials, processing, and properties of permanent magnets. Unlike earlier proceedings, most of the papers are on Nd-Fe-B magnets although Sm-Co magnets are well represented.

Volume II, the Symposium, has 472 pages and is divided into sections dealing with theory and intrinsic material parameters; magnetization process, hardening mechanism, microstructure, and viscosity phenomena; and phase diagrams and microstructure. A wider variety of alloys are reported on in this volume than in the Workshop volume.

## MEETINGS

### W-Ti-RE-Sb '88

The First International Conference on the Metallurgy and Materials of Tungsten, Titanium, Rare Earths, and Antimony will be held November 5-8, 1988, in Changsha, Hunan Province, People's Republic of China. The conference is being organized by The Nonferrous Metals Society of China and The China Society of Rare Earth in collaboration with the Central South University of Technology. An exhibit of domestic and foreign products, technology, modern equipment, and instrumentation will also be held.

Any paper dealing with W, Ti, RE, or Sb will be considered for inclusion, although main emphasis is on extractive metallurgy, production, purification, and application of the elements and their alloys or compounds. The language for abstracts, papers, oral presentations, and discussions is English. Deadline for abstracts to be submitted is January 31, 1988, with accepted papers to be submitted by May 31, 1988.

For further information or to submit an abstract, contact The Conference Secretariat of W-Ti-RE-Sb '88, c/o The Nonferrous Metals Society of China, 9 Xizang Hutong, Xizhimennei Dajie, Beijing, People's Republic of China.

## Magnet Survey

Gorham International Incorporated has completed a "Global Assessment of the Business Impact of High-Tech Neodymium-Iron-Boron Materials on Permanent Magnet Users, Producers, and Raw Materials Suppliers, 1985-1995." This study, completed in October 1986, assesses the worldwide impact of Nd-Fe-B magnets on markets for raw materials, demand for other kinds of magnets, details their use and properties, and examines cost trends and future prospects until 1995.

The cost for this report is \$7,500. A prospectus is available from Mr. Gregory J. Perron, projects director, Gorham International Inc., P.O. Box 8, Gorham, Maine 04038, U.S.A., or Mr. Shigeru Nishiyama, senior consultant, IRM Incorporated, Rosei Building 4-2, Higashi Azabu 1-Chome, Minato-ku, Tokyo 106, Japan.

## MAGNETIC BUBBLES

The evolution of magnetic bubble technology, invented slightly more than 15 years ago, is described in *Magnetic Bubbles*, a book edited by H. Jouve.

The titles and authors of the 5 chapters are as follows: (1) "Garnet Substrates for Magnetic Bubble Films," by C. D. Brandle; (2) "Amorphous Gd-Co Alloys for Magnetic Bubble Applications," by P. Chaudhari, C. H. Bajorek, and M. H. Kryder; (3) "Garnet Films for High Bubble Velocities and High Bubble Mobilities," by D. J. Breed and U. Enz; (4) "Field Access Permalloy Devices," by S. Orihara and T. Yanase; and (5) "Circuit Design and Properties of Patterned Ion-Implanted Layers for Field Access Bubble Devices," by T. J. Nelson and D. J. Muehler. All of the chapters are well referenced to the original literature.

This 295-page book was published in 1986, costs U.S.\$56.00, and may be obtained from Academic Press, Orlando, Florida 32887, U.S.A. or 24/28 Oval Road, London NW1 7DX, U.K.

## Corrosion Inhibitor

B. R. W. Hinton, D. R. Arnott and N. E. Ray [*Metals Forum*, 7 211-7 (1984)] reported that a small amount (100-1000 ppm) of  $CeCl_3$  added to 0.1 molar NaCl solution reduced the corrosion rate of 7075 aluminum alloy by almost a factor of ten.

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## Business News ETREMA

Dale McMasters, general manager of the ETREMA (Edge Technologies Rare Earth Magnetostrictive Alloys) division of Edge Technologies, has announced that Terfenol-D is available from ETREMA, Edge Technologies Incorporated, 306 South 16th Street, Ames, Iowa 50010, U.S.A.

Terfenol-D, a magnetostrictive alloy of terbium, dysprosium, and iron, was developed and characterized by Dr. Arthur Clark at the Naval Surface Weapons Center, Silver Spring, Maryland, and Dale McMasters at the Ames Laboratory, Ames, Iowa. McMasters and his co-workers developed the manufacturing processes that led to the commercialization of these magnetostrictive alloys.

Near single crystal Terfenol-D,  $Tb_{0.8}Dy_{1.2}Fe_2$ , exhibits magnetostrictions of 1,500-2,000 ppm at practical applied fields. Current applications include sonar, vibration and noise level control, micropositioners, pumps, valves, fuel injection systems, robotics, and power transmission.

ETREMA has also announced the appointment of Mel Goodfriend as sales/marketing manager and Richard Coyle as metallurgist.

## Molycorp Expansion

Molycorp, Inc., a wholly-owned subsidiary of the Unocal Corporation, has embarked on a major modernization and expansion program. The program calls for immediate expenditures of \$5 million and up to \$20 million over the next five years. The objective, according to Thomas A. Wilson, senior vice president of Molycorp, is to improve their position in downstream refined materials.

Specifically, the program will double the capacity for high purity cerium at the Mountain Pass, California facility thus freeing the facility at York, Pennsylvania for other high purity materials, triple the capacity for high purity neodymium, double the  $Y_2O_3$  output capacity at Louviers, Colorado and yttrium metal at Washington, Pennsylvania, and add processing equipment at Mountain Pass to supplement production of high purity lanthanum at Louviers. In addition, the program

(Continued in next column)

## HONORS

In addition to winning the Nobel Prize for Physics for their pioneering work in high-T<sub>c</sub> oxide superconductors, J. G. Bednorz and K. A. Müller, along with J. Clarke and J. Kondo were presented Fritz London Memorial Awards at the XVIII Conference on Low Temperature Physics held August 20-26, 1987 in Kyoto, Japan. Clarke won for his work on SQUIDS (superconducting quantum interference devices) and SLUGS (superconducting low-inductance galvanometers) while Kondo was honored for his explanation of the resistance minimum in metallic systems with magnetic impurities.

Harry G. Drickamer [*RIC News*, XXII [1] 2 (1987)] was presented the 1987 Robert A. Welch Award in Chemistry. The award recognizes his discovery of pressure tuning spectroscopy at high pressures, work that has led to major advances in the detailed understanding of molecular, atomic, and electronic properties of matter.

Pierre-Gilles de Gennes, College of France and Ecole de Physique et Chimie, Paris, France, has been elected a foreign associate of The National Academy of Sciences of the United States.

Adam Heller and Albert Narath of AT&T Bell Laboratories have been elected new members of The National Academy of Engineering of the United States.

The Iowa State University (ISU) Alumni Association awarded a Superior Service Award to Lois M. McVicker. Lois is the secretary for RIC. She has been a valuable employee of the center for the past 13 years, and will be missed when she retires January 4, 1988.

The ISU Alumni Association also awarded their highest alumni award, the Distinguished Achievement Citation to Velmer A. Fassel, Ph.D. '47.

The 1987 Mack Memorial Award was presented by the graduate students of Ohio State University to Tobin J. Marks of Northwestern University. The award is given each year in recognition of outstanding contributions to the field of chemistry and to graduate education.

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will upgrade instrumentation, process controls, and other manufacturing steps.

## TETSUHIKO OKAMOTO

We have recently received word of the death of Professor Okamoto, age 61, dean of the faculty of Integrated Arts and Science at Hiroshima University. He was assassinated by (an) unknown person(s) in his office on July 21, 1987.

Born in Hiroshima on December 25, 1925, Professor Okamoto received his undergraduate and graduate education at Hiroshima University, earning his doctorate in 1962. He immediately went to work at the university and, except for a year as visiting professor in physics at the University of Arizona, spent his entire career at Hiroshima University.

He studied the effect of hydrostatic pressure on the magnetic properties of the rare earths. He also studied the magnetic, electrical, crystalline, and mechanical properties of intra rare earth alloys and intermetallic compounds, such as  $RM_2$ , ( $M = Mn, Co, Cu, Ru$ ),  $RM$  ( $M = Ga, Ag, Cd, In$ ) and  $RCo_5$ .

## SHIFT REAGENTS

*Lanthanide Shift Reagents in Stereochemical Analysis* is the title of a book edited by Terence C. Morrill and published in 1986 by VCH Publishers, Inc., 220 East 23rd Street, Suite 909, New York, N.Y. 10010-4606, U.S.A. The 193-page book lists at U.S. \$45.00.

The authors discuss computer-aided approaches to elucidating the geometry of lanthanide shift reagent (LSR)-substrate complexes and show solutions of complex stereochemical problems. Other subjects covered are stereochemical analyses of diastereotopic groups, ring conformations, bridged polycyclic compounds, and deuterium labeling. The book ends with an author index of the references cited and a subject index.

The chapter titles and their authors are: (1) An introduction to lanthanide shift reagents by T. C. Morrill, (2) Computer approaches to the geometry of the LSR-Substrate complex: geometry of shift reagent-substrate complexes. Simulation of induced chemical shifts by J. B. Chiasson and K. Jankowski, (3) The nature of the LSR-substrate complex by D. J. Raber, (4) Solutions to stereochemical problems by J. Paasivirta, and (5) Binuclear lanthanide (III)—silver(I) NMR shift reagents by T. J. Wenzel.

## RE-BYC

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magnetic properties deteriorated.

Hans Stadelmaier (North Carolina State University), who had been investigating rare earth-transition metal-boron systems, was just beginning to work on their magnetic properties. He and his colleagues found a Sm-Co-B compound that was identical to an equilibrium Nd-Fe-B compound reported by crystallographers from Ivan Franko State University, Lvov, Ukraine. In 1983, Stadelmaier identified a compound with the same stoichiometry in an Pr-Fe-B-Si mixture, which had been prepared by George Hadjipanayis of the Kollmorgen Corporation (now at Kansas State University) with a  $BH_m$  of 96 kJ/m<sup>3</sup>.

In June 1983, Sumitomo Special Metals Company of Osaka, Japan, announced a magnet based on a new compound containing Nd and Fe, which was made by the conventional powder techniques used to make Sm-Co magnets, with a  $BH_m$  of 290 kJ/m<sup>3</sup>.

At a meeting in November 1983, Masato Sagawa of Sumitomo gave a detailed description of the process. At the same meeting, Koon described melt-spun Pr-Fe-B and Nd-Fe-B materials at NRL with  $BH_m$  up to 103 kJ/m<sup>3</sup> and Croat discussed their similar melt-spun systems at GM with  $BH_m$  up to 120 kJ/m<sup>3</sup>. Croat also reported they had found a way to double this value but did not give details.

In January 1984, Crucible's Research Center in Pittsburgh announced researchers there had made a magnet material by a powder metallurgical method with the highest  $BH_m$  yet, 341 kJ/m<sup>3</sup>.

The impact of the Nd-Fe-B magnets will depend on both technological and economic factors. The most likely development, according

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## \*\*SPONSORS\*\*

The second quarter of fiscal year 1988 was relatively quiet but combined with the first quarter put us about where we were last year. Research Chemicals became the third 20-year member of our sponsoring family while we added 3 new family members. The 16 companies pledging their support this quarter, with the number of years they have been sponsors in parentheses, are listed below.

Astronautics Corporation of America, U.S.A. (2)  
Auer-Remy GmbH, West Germany (1)  
CANMET, Canada (1)  
Companhia Industrial Fluminense, Brazil (15)  
Hazen Research Incorporated, U.S.A. (2)  
Howmet Turbine Components Corporation, U.S.A. (2)  
Indian Rare Earths Limited, India (19)  
Kobe Development Corporation, U.S.A. (2)  
LDJ Incorporated, U.S.A. (1)  
Mitsubishi Chemical Industries Limited, Japan (14)  
Nippon Steel Corporation, Japan (2)  
Research Chemicals, A Division of NUCOR Corporation, U.S.A. (20)  
Rhone Poulenc Incorporated, U.S.A. (8)  
Shin-Etsu Chemical Industry Company, Limited, Japan (18)  
Sumitomo Special Metals Company, Limited, Japan (3)  
Wako Bussan Company, Limited, Japan (19)

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to Karl Strnat, is the development of a large family of magnets with varying compositions with Nd-Fe-B magnets at one extreme and Sm-Co magnets at the other.