# 100 YEARS OF SUPERCONDUCTIVITY

Edited by
Horst Rogalla and Peter H. Kes

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A TAYLOR & FRANCIS BOOK

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742



Printed and bound in India by Replika Press Pvt. Ltd.
Version Date: 20110811

International Standard Book Number: 978-1-4398-4946-0 (Hardback)



**Library of Congress Cataloging-in-Publication Data**

100 years of superconductivity / editors, Horst Rogalla, Peter H. Kes.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4398-4946-0 (hardback)
1. Superconductors--Research--History. 2. Superconductors--Industrial applications. I. Rogalla, H. (Horst) II. Kes, P. H. (Peter H.) III. Title: One hundred years of superconductivity.

QC611.96.A16 2011
537.6'23--dc23 2011030774

**Visit the Taylor & Francis Web site at**
**http://www.taylorandfrancis.com**

**and the CRC Press Web site at**
**http://www.crcpress.com**

# *Contents*

# *Preface*

Superconductivity came as a big surprise. But more amazing perhaps is that even a hundred years after its discovery this peculiar phenomenon continues to bring us new surprises. The research of superconductivity is characterized by times of relative quietness, interrupted by periods of exciting activities, often preceded by fundamental breakthroughs that later won Nobel Prizes in physics or chemistry. "Fundamental" can in this case both relate to an emerging theoretical insight and to a new class of materials displaying entirely unforeseen properties. In both cases, the prospect of new applications has been an important drive for commercial ambitions.

In the meantime, applications of superconductivity have found a place in science and industry; just like superconductivity in general, there were periods of quiet progress and stormy phases, but overall a steady progress took place, e.g., high-$T_c$ superconductors were judged in the beginning as "never applicable in high magnetic fields" because of their grain boundary problem. In the meantime, they are essential building blocks for the creation of very high permanent fields: the result of excellent ideas and the cooperation between fundamental and applied scientists. Superconducting magnets for MRI can be found in any major hospital, and high-energy physics without superconducting magnets is practically unthinkable.

A similar breathtaking development took place in superconducting electronics: quantum-limited detectors, quantum-information processing, MEG and MCG, high-speed computing, and analog-to-digital and digital-to-analog converters with quantum precision, incorporating tens of thousands of Josephson junctions, are available. It seems to be a question only of time (and cooling) until they will enter the industrial product cycle.

In this centennial book on superconductivity many authors who themselves were responsible for the important steps forward, or were very close to those pioneers, report on the historical developments. The contributions represent their personal views and therefore this book does not provide the ultimate answers to all questions about superconductivity. Nonetheless it has become a very interesting collection of recollections and reviews of almost all the subdisciplines of superconductivity. The first three chapters concentrate on the interesting stories of the discovery and the succeeding gradual progress of theory and experiment. Much emphasis is given to the important developments in the early 1950s and 1960s. From then on superconductivity started to penetrate society and most applications today are based on the innovations of those years. But long before superconductivity could celebrate its centennial, a genuine revolution occurred with the discovery of the high temperature superconductors. A new episode began which is nicely described in a number of articles that bring this book up to the present time.

Originally it was the intention to present a small booklet (about 50 pages) to the attendants of the Superconductivity Centennial Conference taking place in the Netherlands in September 2011. This project quickly grew out to a book project of now more than 800 pages — primarily due to the excitement of scientists and engineers intending to show how far superconductivity has come after 100 years. Due to the limitation in space we had to restrict the number of contributions and many famous colleagues who would have deserved to take part in the project had to be left out. Even extending the size of the book to more than 800 pages did not help — superconductivity has become a vast field.

Being editors of the book was an exciting task, extremely enjoyable and nerve-wracking — hard deadlines melt in the sun of wonderful science and engineering! And preparing a book in LaTeXwas an experience on its own. The help of students of the University of Twente (M. Garcia, W.A.G. Vessies, S. Waanders) and of the CU in Boulder (P. Lippert) is appreciated. The work of Daan Boltje in Leiden, Troy Christensen in Houston, and Peter Lee and Dmytro Abraimov in Tallahassee was essential to finish chapters 1, 2, 4 and 11. Finally our thanks to all authors, who were too engaged to stick to the page limits, and to the section editors, who did a wonderful (and difficult) job to organize and edit their chapters and to keep the excitement of the authors in balance with the available space in the book.

Horst Rogalla and Peter H. Kes

# List of Authors

## Editors

Horst Rogalla
University of Twente
Enschede
The Netherlands

Peter H. Kes
Kamerlingh Onnes Laboratory
Leiden University
Leiden
The Netherlands

## Chapter 1

Peter H. Kes (editor)
Kamerlingh Onnes Laboratory
Leiden University
Leiden
The Netherlands

Rudolf de Bruyn Ouboter
Kamerlingh Onnes Laboratory
Leiden University
Leiden
The Netherlands

Dirk van Delft
Boerhaave Museum
Leiden
The Netherlands

A. B. Pippard (deceased)
Cavendish Laboratory
Cambridge
England

## Chapter 2

Jan Zaanen (editor)
Instituut-Lorentz for
Theoretical Physics
Leiden University
Leiden
The Netherlands

David Pines
ICAM and Physics Department
U C Davis
Davis, CA
USA

A. E. Koshelev
Materials Science Division
Argonne National Laboratory
Argonne, IL
USA

V. M. Vinokur
Materials Science Division
Argonne National Laboratory
Argonne, IL
USA

Lev P. Gor'kov
NHMFL
Florida State University
Tallahassee, FL
USA

Ernst Helmut Brandt
Max Planck Institute for Metals
Research
Stuttgart
Germany

T. I. Baturina
Materials Science Division
Argonne National Laboratory
Argonne, IL
USA

L. N. Bulaevskii
Los Alamos National Laboratory
Los Alamos, NM
USA

R. P. Huebener
Eberhard Karls Universität
Tübingen
Germany

### Chapter 3

J. Mannhart (editor)
Max Planck Institute for Solid State Research
Stuttgart
Germany

C. C. Tsuei
IBM Thomas J. Watson Research Center
Yorktown Heights, NY
USA

D. Dimos
Engineering Sciences Center
Sandia National Laboratories
Albuquerque, NM
USA

John M. Rowell
Arizona State University
Tempe, AZ
USA

J. R. Kirtley
Center for Probing the Nanoscale
Stanford University
Stanford, CA
USA

M. R. Beasley
Stanford University
Stanford, CA
USA

Dietrich Einzel
Walther-Meissner Institut
Garching
Germany

Jean-Marc Triscone
University of Geneva
Geneva
Switzerland

Eli Zeldov
Weizmann Institute of Science
Rehovot
Israel

Dale J. Van Harlingen
University of Illinois at Urbana-Champaign
Champaign, IL
USA

Marc Gabay
Université Paris-Sud
Orsay
France

### Chapter 4

C. W. Chu (editor)
University of Houston
Houston, TX
and Lawrence Berkeley National Laboratory
Berkeley, CA
USA

Takahiro Muranaka
Aoyama Gakuin University
Tokyo
Japan

K. Shimizu
Osaka University
Osaka
Japan

A. Bussmann-Holder
Max-Planck Institut für Festkörperforschung
Stuttgart
Germany

Jun Akimitsu
Aoyama Gakuin University
Tokyo
Japan

F. Steglich
Max Planck Institute for Chemical Physics of Solids
Dresden
Germany

K. A. Müller
Physik Institut der Universität Zürich
Zürich
Switzerland

Kosmas Prassides
Department of Chemistry
Durham University
Durham
UK

Yoshiteru Maeno
Kyoto University
Kyoto
Japan

David C. Johnston
Ames Laboratory and Department of Physics and Astronomy
Iowa State University
Ames, IA
USA

Matthew J. Rosseinsky
Department of Chemistry
University of Liverpool
Liverpool
UK

M. Brian Maple
Department of Physics
University of California at San Diego
La Jolla, CA
USA

Hideo Hosono
Tokyo Institute of Technology
Tokyo
Japan



### Chapter 5

A. I. Braginski (editor)
Forschungszentrum Jülich
Jülich
Germany

C. P. Foley
Commonwealth Scientific and Industrial Research Organization (CSIRO)
Lindfield
Australia

Kent Irwin
National Institute of Standards and Technology (NIST)
Boulder, CO
USA

John Clarke
University of California at Berkeley and Lawrence Berkeley Laboratory
Berkeley, CA
USA

Ronald E. Sager
Quantum Design
San Diego, CA
USA

Peter Michelson
Stanford University
Stanford, CA
USA

Arnold Silver
Rancho Palos Verdes, CA
USA

### Chapter 6

J.E. Mooij (editor)
Kavli Institute of Nanoscience
Delft University of Technology
The Netherlands

### Chapter 7

Shinya Hasuo (editor)
ISTEC
Tokyo
Japan

Horst Rogalla
University of Twente
Enschede
The Netherlands

Akira Fujimaki
University of Nagoya
Nagoya
Japan

Theodore Van Duzer
University of California at Berkeley
Berkeley, CA
USA

Mutsuo Hidaka
ISTEC
Tokyo
Japan

Oleg Mukhanov
HYPRES
Elmsford, NY
USA

Fernand (Doc) Bedard
National Security Agency (NSA)
Silver Spring, MD
USA

## Chapter 8

D. E. Oates (editor)
MIT Lincoln Laboratory
Lexington, MA
USA

R. B. Hammond
Superconductor Technologies Inc.
Santa Barbara, CA
USA

N. O. Fenzi
Superconductor Technologies Inc.
Santa Barbara, CA
USA

B. A. Willemsen
Superconductor Technologies Inc.
Santa Barbara, CA
USA

T. M. Klapwijk
Kavli Institute of Nanoscience
Delft University of Technology
The Netherlands

W. D. Oliver
MIT Lincoln Laboratory
Lexington, MA
USA

Jonas Zmuidzinas
NASA Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA
USA

## Chapter 9

Richard E. Harris (editor)
National Institute of Standards and Technology
Boulder, CO
USA

Jaw-Shen Tsai
RIKEN/NEC
Tsukuba
Japan

James E. Lukens
SUNY
Stony Brook, NY
USA

Thomas J. Witt
Bureau International des Poids et Mesures
Sèvres
France

Jürgen Niemeyer (editor)
Physikalisch-Technische Bundesanstalt
Braunschweig
Germany

Tadashi Endo
MTA Japan Ltd.
Tokyo
Japan

Clark A. Hamilton
National Institute of Standards and Technology
Boulder, CO
USA

Johannes Kohlmann
Physikalisch-Technische Bundesanstalt
Braunschweig
Germany

Samuel P. Benz
National Institute of Standards and Technology
Boulder, CO
USA

Edwin Williams
National Institute of Standards and Technology
Gaitherburg, MD
USA

Ian Robinson
National Physical Laboratory
Teddington
UK

## Chapter 10

Harold Weinstock (editor)
US Air Force Office of Scientific Research
Arlington, VA
USA

Cosimo Del Gratta
Gabriele D'Annunzio University
Chieti
Italy

Stefania Della Penna
Gabriele D'Annunzio University
Chieti
Italy



Vittorio Pizzella
Gabriele D'Annunzio University
Chieti
Italy

Gian-Luca Romani
Gabriele D'Annunzio University
Chieti
Italy

Riccardo Fenici
Catholic University of Rome
Rome
Italy

Donatella Brisinda
Catholic University of Rome
Rome
Italy

Anna Rita Sorbo
Catholic University of Rome
Rome
Italy

Angela Venuti
Catholic University of Rome
Rome
Italy

Jim Bray
GE Global Research
Albany, NY
USA

Kathleen Amm
GE Global Research
Albany, NY
USA

John Clarke
University of California at Berkeley and Lawrence Berkeley Laboratory
Berkeley, CA
USA

Peter A. Zavodszky
GE Global Research
Albany, NY
USA

## Chapter 11

David Larbalestier (editor)
National High Magnetic Field Laboratory
Tallahassee, FL
USA

Peter J. Lee
National High Magnetic Field Laboratory
Tallahassee, FL
USA

Bruce Strauss
U. S. Department of Energy
Washington, DC
USA

Kyoji Tachikawa
Tokai University
Tokai
Japan

Martin W. Rupich
American Superconductor Corporation
Devens MA
USA

Eric E. Hellstrom
National High Magnetic Field Laboratory
Tallahassee, Florida
USA

A. P. Malozemoff
American Superconductor Corporation
Devens MA
USA

Y. Yamada
ISTEC
Tokyo
Japan

René Flükiger
University of Geneva
Geneva
Switzerland

Hiroaki Kumakura
National Institute for Materials Science
Tsukuba
Japan

## Chapter 12

Peter Komarek (editor)
Karlsruhe Institute of Technology (KIT)
Karlsruhe
Germany

Bruce Strauss (editor)
U. S. Department of Energy
Washington, DC
USA

Steve St. Lorant (editor)
SLAC National Accelerator Laboratory
Menlo Park, CA
USA

Luca Bottura (editor)
CERN
Geneve
Switzerland

Al McInturff (editor)
Texas A&M University
College Station, TX
USA

Steve A. Gourlay
Lawrence Berkeley National Laboratory
Berkeley, CA
USA

Lucio Rossi
CERN
Geneve
Switzerland

Jean-Luc Duchateau
CEA
Cadarache
France

Bernard Turck
CEA
Cadarache
France

William Hassenzahl
Advanced Energy Analysis
Las Vegas, NV
USA

Osami Tsukamoto
Faculty of Engineering
Yokohama National University
Yokohama
Japan

Christopher M. Rey
Oak Ridge National Laboratory
Oak Ridge, TN
USA

Niklas Magnusson
SINTEF Energy Research
Trondheim
Norway

Larry Masur
Zenergy Power, Inc.
Burlingame, CA
USA

Gerhard Roth
Bruker Biospin
Rheinstetten
Germany

# Glossary

## Glossary of Frequently Used Acronyms, Symbols, Terms and Physical Constants

We list here the fundamental physical constants, symbols, terms and also acronyms appearing throughout this book. Some of the terms, necessary to understand this book, are briefly defined.

### Fundamental Physical Constants

| | |
|---|---|
| $c = 2.997925 \times 10^{8}$ m/s | velocity of light |
| $e = 1.6022 \times 10^{-19}$ C | electron charge |
| $h = 6.6261 \times 10^{-34}$ Js | Planck constant |
| $N_A$ | Avogadro constant |
| $\hbar = h/2\pi = 1.0546 \times 10^{-34}$ Js | Planck constant |
| $\Phi_0 \equiv h/2e = 2.0678 \times 10^{-15}$ Vs | flux quantum |
| $k_\mathrm{B} = 1.3807 \times 10^{-23}$ J/K | Boltzmann constant |
| $\epsilon_0 = 8.8542 \times 10^{-12}$ As/Vm | permittivity of vacuum |
| $\mu_0 = 4\pi \times 10^{-7}$ Vs/Am | permeability of vacuum |

### Symbols and Terms

| | |
|---|---|
| $\mathbf{A}$ | vector potential (vectors are denoted by bold, Roman symbols) |
| $\mathbf{B}$ | magnetic induction, $\mathbf{B} = \mathrm{curl}\,\mathbf{A}$ |
| $\mathbf{H}$ | magnetic field |
| $\mathbf{E}$ | electric field |
| $B = \|\mathbf{B}\|$ | magnetic induction (magnitude) |
| $H = \|\mathbf{H}\|$ | magnetic field (magnitude) |
| $E = \|\mathbf{E}\|$ | electric field (magnitude) |
| $c$ | specific heat |
| $H_\mathrm{c}$ | thermodynamic critical field |
| $H_{\mathrm{c}1}$ | lower critical field, field at which flux penetrates into a type II superconductor |
| $H_{\mathrm{c}2}$ | upper critical field, field at which the normal state comes back. Between $H_{\mathrm{c}1}$ and $H_{\mathrm{c}2}$ the material is in the Shubnikov phase (mixed state) |
| $\lambda$ | magnetic penetration depth |
| $\lambda_\mathrm{L}$ | London penetration depth |
| $\xi_0$ | coherence length, size of a Cooper pair |
| $\xi$ | Ginzburg-Landau coherence length, length scale describing variation of |

| | |
|---|---|
| | Cooper pair density |
| $\kappa$ | Ginzburg-Landau parameter, $\kappa = \lambda/\xi$, parameter distinguishing between type I and type II superconductors |
| $\beta_A$ | Abrikosov parameter, determines the structure of the Abrikosov vortex lattice |
| $a_0$ | lattice parameter of Abrikosov vortex lattice |
| $\sigma$ | electric conductivity |
| $\rho$ | electric resistivity |
| $l$ | electron mean free path |
| $F, f$ | Helmholz free energy, Helmholz free energy density |
| $m$ | electron mass |
| $n_s$ | density of superconducting electrons |
| $\mathbf{v}_s$ | average velocity of superconducting electrons |
| $\mathbf{p}_s$ | momentum of superconducting condensate |
| $\mathbf{v}_F, \mathbf{p}_F$ | Fermi velocity, Fermi momentum |
| $\epsilon_F, E_F$ | Fermi energy |
| $N(E_F)$ | density of electronic states at the Fermi energy |
| $\mathbf{j}, \mathbf{J}$ | electric current density |
| $\Delta_\chi$ | generalized phase difference over Josephson junction |
| $\gamma$ | Sommerfeld constant of electron specific heat |
| $\Delta(T)$ | temperature dependent energy gap |
| $V$ | BCS parameter determining the strength of the electron-phonon interaction |
| $\omega_D$ | Debye frequency |
| $\omega_P$ | Josephson plasma frequency |
| $\gamma$ | anisotropy parameter of a layered superconductor |
| $J_0$ | interlayer Josephson critical current |
| $\lambda_J$ | Josephson length |
| $s$ | layer thickness in a layered superconductor |
| $\Phi_{\alpha\beta}$ | elastic matrix of a vortex lattice |
| $b$ | reduced magnetic induction, $b = H/H_{c2}$ |
| $c_{ii}$ | elastic moduli of a vortex lattice |
| $c_{11}$ | uniaxial compression modulus |
| $c_{44}$ | tilt modulus |
| $c_{66}$ | shear modulus |
| $\eta$ | friction coefficient of a moving vortex lattice |
| $\kappa$ | heat conductivity |
| $\nu$ | Nernst coefficient |
| $\beta_{dc} \equiv 2LI_c/\Phi_c$ | dc SQUID parameter |
| $\beta_{rf} \equiv 2\pi LI_c/\Phi_0$ | rf SQUID parameter |
| $C$ | electric capacitance, heat capacity |
| $\delta \equiv \varphi_1 - \varphi_2$ | phase difference across a Josephson junction |
| $E$ | energy |



| | |
|---|---|
| $\epsilon(f)$ | energy resolution of a SQUID |
| $f$ | frequency |
| $\Phi$ | magnetic flux |
| $\phi(r,t)$ | phase of the function of state |
| $I$ | electric current |
| $I_B, I_b$ | bias current |
| $I_0, I_c$ | critical current (at which, for given $B$ and $T$ the superconductor normalizes) |
| $I_c$ | critical current |
| $J_c$ | critical current density |
| $J_{Cu}$ | current density in the copper |
| $J_e$ | engineering critical current density |
| $J_{overall}$ | overall current density |
| $L$ | electric inductance |
| $\omega$ | angular frequency |
| $\omega_c$ | cutoff or critical frequency |
| $\Psi(\mathbf{r},t) = \lvert\Psi(\mathbf{r},t)\rvert \exp[i\phi(\mathbf{r},t)]$ | macroscopic function of state |
| $\mathbf{r}$ | space vector |
| $R, r$ | electric resistance |
| $R_n$ | normal state resistance of a Josephson junction |
| $S_B$ | spectral density of magnetic field noise |
| $S_\Phi(f)$ | spectral density of the flux noise |
| $S_I(f)$ | spectral density of current noise |
| $S_V(f)$ | spectral density of voltage noise |
| $T_c$ | critical temperature (of transformation to superconducting state below $T_c$) |
| $T_N$ | noise temperature of an electric device, circuit |
| $t$ | time |
| $\tau$ | time constant |
| $V, U$ | electric voltage |
| $V_\Phi$ | flux-to-voltage transfer coefficient (of a SQUID) |
| $V_g$ | energy gap voltage |

## Acronyms

| | |
|---|---|
| **2212** | $Bi_2Sr_2CaCu_2O_{8+X}$ ($X$ denotes deviation from stoichiometry) |
| **2223** | $Bi_2Sr_2Ca_2Cu_3O_{10+X}$ |
| **1G** | 1st generation $Bi_2Sr_2Ca_2Cu_3O_{10+x}$ wire |
| **2G** | 2nd generation $YBa_2Cu_3O_{7-x}$ coated wire |
| **A15 compounds** | a group of superconducting chemical compounds |
| **AC, ac** | alternating current |
| **ACJVS, ac** | Josephson voltage standard |

| | |
|---|---|
| **ADC** | analog to digital converter |
| **ADR** | all-digital receiver |
| **AEC** | alkaline earth cuprate phase in BSCCO system |
| **APC** | artificial pinning center |
| **BCS** | Bardeen-Cooper-Schriefer theory of superconductivity |
| **Bi-2201** | $Bi_2Sr_2CuO_{6+X}$ |
| **BSCCO** | superconductors in the Bi-Sr-Ca-Cu-O system |
| **BW** | bandwidth |
| **BZO** | barium zirconate |
| **CC** | correction coils in a tokamak |
| **CICC** | cable-in-conduit conductor (cables of strand inside tube through which He coolant flows) |
| **CDMC** | old dark matter |
| **CF** | copper free phase in BSCCO system |
| **CMB** | cosmic microwave background (radiation) |
| **CMS** | compact muon solenoid |
| **CPW** | coplanar waveguide |
| **CQOS** | complementary quasione junction SQUID |
| **CS** | central solenoid, in a tokamak |
| **CT-OP** | controlled over-pressure processing—process used by Sumitomo Electric for 1G processing |
| **CVD** | chemical vapor deposition |
| **CW** | continuous wave |
| **DC, dc** | direct current |
| **DE** | dark energy |
| **dipole** | beam-bending electromagnet with two poles; the $b_1$ normal multipole coefficient in the expansion of the complex magnetic field |
| **dodecapole** | the $b_6$ normal multipole coefficient in the expansion of the complex magnetic field; a magnet with twelve poles |
| **DVM** | digital voltmeter |
| **EB** | electron beam |
| **EMI** | electromagnetic interference |
| **EPR** | electron spin paramagnetic resonance |
| **FCL** | fault current limiter |
| **FEL** | free electron laser |
| **FET** | field effect transistor |
| **FWHM** | full width half maximum |
| **FPGA** | field programmable gate array |
| **GB** | grain boundary (usually in high-temperature superconductor) |
| **GLAG** | Ginzburg-Landau-Abrikosov-Gorkov theory of superconductivity |
| **G-M** | Gifford-McMahon |



| | |
|---|---|
| **GZO** | gadolinium zirconate |
| **HEMT** | high electron mobility transistor |
| **Hexed** | filaments drawn through hexagonal die so that they can be stacked efficiently |
| **HF, hf** | high frequency |
| **HTS** | high-temperature superconductor (cuprate) |
| **I** | insulator |
| **IBAD** | ion beam-assisted deposition |
| **IC** | integrated (electric) circuit |
| **ID** | Inside diameter |
| **IR** | infrared |
| **IT** | internal tin process for making $Nb_3Sn$ strand |
| **JJ** | Josephson junction |
| **JNT** | Johnson noise thermometry |
| **JVS** | Josephson voltage standard |
| **LED** | light emitting diode |
| **LHe** | liquid helium |
| **$LN_2$** | liquid nitrogen |
| **LTS** | low-temperature superconductor |
| **MCG** | magnetocardiography (biomagnetic imaging of heart fields/currents) |
| **MEG** | magnetoencephalography (biomagnetic imaging of brain fields/currents) |
| **MFL** | magnetic flux leakage NDE technique |
| **MHD** | magnetohydrodynamic(s) |
| **MIITS** | The energy balance defining the basic parameters for quench protection in a magnet, unit thereof |
| **MOCVD** | metal-organic chemical vapor deposition |
| **MOD** | metal-organic deposition |
| **MPMS** | magnetic property measuring system |
| **MRI** | magnetic resonance imaging |
| **N** | normal conductor |
| **NDE** | nondestructive evaluation (of materials and structures) |
| **NMR** | nuclear magnetic resonance |
| **octupole** | The $b_4$ normal multipole coefficient in the expansion of the complex magnetic field; a magnet with eight poles |
| **OD** | outside diameter |
| **OFHC Cu** | oxygen-free high conductivity copper |
| **OP** | overpressure processing — used for BSCCO conductors |
| **OPIT** | oxide powder in tube |
| **PAIR** | preanneal intermediate rolling — process to make 2212 conductor developed by NRIM |
| **pancakes** | planar magnetic coils |
| **PECVD** | plasma enhanced chemical vapor deposition |

| | |
|---|---|
| **PF** | poloidal-field coils, in a tokamak |
| **pinning** | effect used to inhibit movement of flux lines (vortices) |
| **PJVS** | programmable Josephson voltage standard |
| **PLD** | pulsed laser deposition |
| **PMD** | phase modulation-demodulation |
| **PIT** | powder in tube |
| **quadrupole** | The $b_2$ normal multipole coefficient in the expansion of the complex magnetic field; a magnet with four poles |
| **QOS** | quasi-one Junction SQUID |
| **Quench** | superconducting magnet enters non-superconducting state |
| **QRQ** | quarter rate quantizer |
| **QVNS** | quantized voltage noise source |
| **RABiTS$^{TM}$** | rolling assisted bi-axially textured substrate |
| **REBCO** | rare-earth cuprate (generic) |
| **RF, rf** | radio frequency |
| **rms** | root-mean-square |
| **ROSAT** | rotation-symmetric arragned tape-in-tape — conductor geometry for 2212 conductors developed by Hitachi |
| **RRP$^{TM}$** | rod restacked process, an IT $Nb_3Sn$ strand design developed by OST |
| **RRR** | residual resistivity ratio |
| **RSFQ** | rapid single flux quantum |
| **RSJ** | resistively shunted junction (free of hysteresis Josephson tunnel junction) |
| **S** | superconductor |
| **SASE** | self-amplified stimulated emission |
| **SC** | superconducting; superconductor |
| **SCFCL** | superconducting fault current limiter |
| **sextupole** | The $b_3$ normal multipole coefficient in the expansion of the complex magnetic field; magnet with six poles |
| **SF** | self field |
| **SFQ** | single flux quantum |
| **SINIS** | superconductor-insulator-normal-insulator-superconductor |
| **SIS** | superconductor-insulator-superconductor (tunnel junction, trilayer) |
| **SLUG** | superconducting low-inductance undulatory galvanometer |
| **SMES** | superconducting magnetic energy storage |
| **SNS** | superconductor–normal conductor–superconductor (proximity junction, trilayer) |
| **SNR** | signal-to-noise ratio |
| **SQUID** | superconducting quantum interference device |
| **SCCO/Ag** | bismuth strontium calcium copper oxide superconductor. The Ag indicates the substrate. |
| **SRF** | superconducting radio frequency |
| **STO** | $SrTiO_3$ (strontium titanate) |
| **SZE** | Sunyaev-Zel'dovich effect |



| | |
|---|---|
| **TEM** | transmission electron microscopy |
| **TEM** | transient electromagnetics (geophysical exploration method) |
| **TES** | transition-edge sensor (superconducting detector of energy change) |
| **TF** | toroidal (magnetic) field in a tokamak |
| **TDC** | time to digital converter |
| **V/F** | voltage to frequency |
| **WIMP** | weakly interacting massive particle |
| **YBCO** | $YBa_2Cu_3O_{7-x}$ |
| **YSZ** | yttria stabilized zirconia |

## Institution, Experiment and Instrument Acronyms

| | |
|---|---|
| **AI** | Atomics International |
| **AIST** | National Institute of Advanced Industrial Science and Technology, Japan |
| **AMSC** | American Superconductor Corporation |
| **ANL** | Argonne National Laboratory |
| **ASC** | Applied Superconductivity Conference |
| **BIPM** | Bureau International des Poids et Mesures, Paris, France |
| **BNL** | Brookhaven National Laboratory |
| **BOC** | British Oxygen Company |
| **BTL** | Bell Telephone Laboratories |
| **CEA** | Commissariat à l'Energie Atomique et aux Energies Alternatives, France |
| **CEBAF** | Colliding Electron Beam Facility |
| **CEGB** | Central Electricity Generating Board (UK) |
| **CERN** | European Organization for Nuclear Research |
| **CESR** | Cornell electron positron storage ring |
| **CGPM** | General Conference on Weights and Measures |
| **CSIRO** | Commonwealth Scientific and Industrial Research Organization, Australia |
| **DESY** | Deutsches Elektronen-Synchrotron |
| **DOE** | US Department of Energy |
| **EAST** | Experimental Advanced Superconducting Tokamak: Chinese experimental tokamak |
| **EPAC** | European Particle Accelerator Conference |
| **ESCAR** | Experimental Superconducting Electron Ring, at LBL |
| **ETL** | Electrotechnical Laboratory, Japan; former name of AIST |
| **FLUXONICS** | European network for superconducting electronics |
| **FNAL** | Fermilab (Fermi National Accelerator Laboratory) |
| **FSU** | Florida State University |
| **FZ-Karlsruhe** | Forschungs zentrum Karlsruhe, Germany. Renamed KIT, Karlsruhe Institut für Technologie |
| **GE** | General Electric Corporation |
| **GSI** | Helmholtzzentrum (Gesellschaft) für Schwerionenforschung, Darmstadt |

| | |
|---|---|
| **Harwell** | United Kingdom Atomic Energy Authority (UKAEA) Research Establishment at Harwell |
| **HEP** | high energy physics |
| **HERA** | Hadron Electron Ring Accelerator, at DESY, Deutches Elektronen-Synchrotron |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IGC** | Intermagnetics General Corporation. |
| **IMI** | Imperial Metal Industries |
| **IPHT** | Institute für Photonishe Technologien, Germany |
| **IPK** | International Prototype of the Kilogram |
| **IPP** | Max Planck Institute for Plasmaphysics, "Institut für Plasmaphysik" |
| **IREE** | Institute for Radio Electronics and Engineering |
| **ISABELLE** | Intersecting Storage Accelerator + "belle" at BNL |
| **ISTEC** | International Superconductivity Technology Center (Tokyo) |
| **ITER** | International Thermonuclear Experimental Reactor |
| **IUPAP** | International Union of Pure and Applied Physics |
| **J-PARC** | Japan Proton Accelerator Research Complex |
| **JAERI** | Japan Atomic Energy Research Institute |
| **JINR** | Joint Institute for Nuclear Research, Dubna, Russia |
| **JLAB** | Thomas Jefferson National Accelerator Facility (TJNAF) |
| **JT-60SA** | Experimental tokamak program preceding ITER, in Japan |
| **KAERI** | Korea Atomic Energy Research Institute |
| **KAIST** | Korea Advanced Institute of Science and Technology |
| **KEK** | High Energy Accelerator Research Organization, Japan |
| **KERI** | Korea Electro-Technology Research Institute |
| **KSTAR** | Korea Superconducting Tokamak Advanced Research |
| **LAMPF** | Los Alamos Meson Physics Facility |
| **LASL** | Los Alamos Scientific Laboratory, now LANL, ("National") |
| **LBNL/LBL** | Lawrence Berkeley National Laboratory |
| **LEP** | large electron positron collider, CERN |
| **LHC** | large hadron collider, CERN |
| **LHD** | large helical device superconducting: stellarator in operation in Japan |
| **MCA** | Magnetic Corporation of America |
| **METAS** | Federal Office of Metrology, Switzerland |
| **MIT** | Massachusetts Institute of Technology |
| **MSU** | Michigan State University (location of National Superconducting Cyclotron Laboratory, NSCL) |
| **MSU** | Moscow State University |
| **NAL** | National Accelerator Laboratory (founded 1967), renamed Fermilab in 1974 |
| **NBS** | National Bureau of Standards, USA; former name of NIST |
| **NIST** | National Institute of Standards and Technology, USA |
| **NMI** | National Measurement Institute |



| | |
|---|---|
| **NML** | Former name of national measurement institute in Australia |
| **NPL** | National Physical Laboratory, Great Britain |
| **NRIM/NIMS** | National Research Institute for Metals, now National Institute for Materials Science (Japan) |
| **NST/NKT** | Nordic Superconductor Technologies A/S is a subsidiary of Denmark's NKT Holding A/S |
| **OI** | Oxford Instruments |
| **ORNL** | Oak Ridge National Laboratory |
| **PTB** | Physikalisch-Technische Bundesanstalt |
| **RCA** | Radio Corporation of America |
| **RHIC** | Relativistic heavy ion collider (at BNL) |
| **RMI** | Formerly Reactive Metals, Inc., now RMI Titanium Company Extrusion Plant |
| **Rutherford** | Rutherford Appleton Laboratory (RAL) — when not referring to physicist Ernest Rutherford |
| **SI** | International system of units |
| **SIS** | Schwerionen Synchroton at GSI, Darmstadt, Germany |
| **SNS** | spallation neutron source |
| **SSC** | superconducting super collider |
| **SST1** | Experimental tokamak in India with superconducting components |
| **SEI** | Sumitoma Electric Industries |
| **Tevatron** | Adopted name for the Energy Saver/Doubler hadron collider at FNAL |
| **Tore Supra** | Combination of "torus" and "superconductor," a French tokamak |
| **TOSKA** | Usually understood to be a composite of "tokamak," "supraleiter" and "Karlsruhe," Germany, a test facility |
| **TRIAM** | Tokamak at the Research Institute for Applied Mechanics (RIAM) at Kyushu University, Japan |
| **UNK** | Accelerator at JINR, Dubna, Russia. Acronym unknown |
| **UTSI** | University of Tennessee Space Institute |
| **W7-X** | Wendelstein 7-X: superconducting stellarator under construction in Germany |
| **WDG** | Wire Development Group — research collaborations organized by American Superconductor Corp. that has worked on 1G and 2G wire |