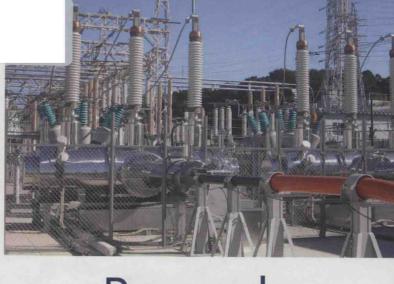
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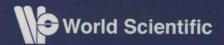
Superconductivity and Related Phenomena

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Research,
Fabrication and
Applications of
Bi-2223 HTS Wires

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VOL 📹

# Research, Fabrication and Applications of Bi-2223 HTS Wires

Edited by

Kenichi Sato

Sumitomo Electric Industries Ltd, Japan



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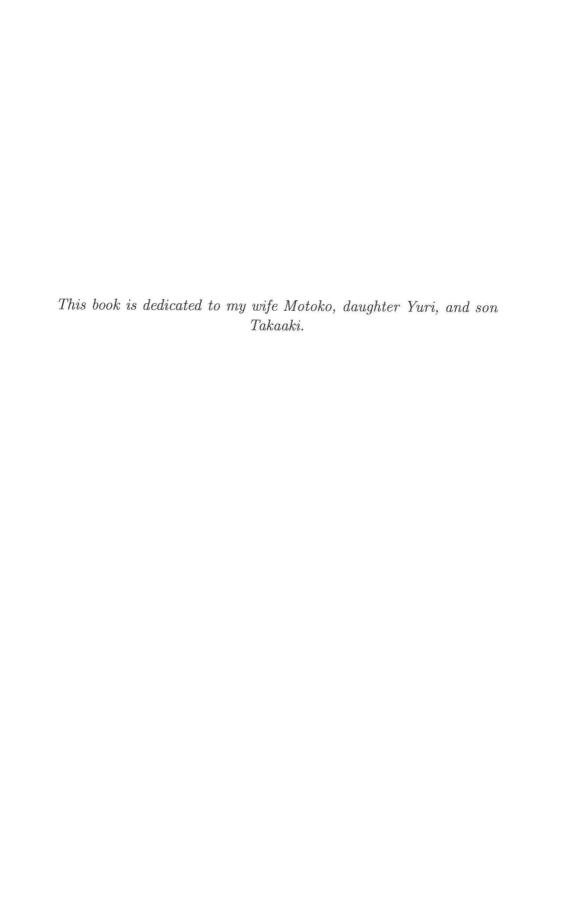
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Forthcoming

 ${\rm MgB_2}$  Superconducting Wires: Basics and Applications edited by René Flükiger



## Preface

Prof. Guy Deutscher serves as scientific Editor-in-Chief of a new series of "Applications of Superconductivity". He wishes to acknowledge the help of the Executive Committee of the IEA Agreement on Superconductivity in preparation of this Series. This book is focusing on Bi-2223. Bi-Sr-Ca-Cu-O oxide superconducting material (BSCCO) was discovered on Christmas Eve, 24<sup>th</sup> December, 1987 by Dr. Hitoshi Maeda, et al. There are three compounds in the BSCCO system, and Bi-2223 (Bi<sub>2</sub>Sr<sub>2</sub>Ca<sub>2</sub>Cu<sub>3</sub>O<sub>10</sub>) has the highest critical temperature of around 110 K. Bi-2223 has many features; not only high critical temperature but also non-rare earth elements, and well aligned crystals through mechanical deformation.

Around 28 years have passed since the discovery of BSCCO. There are so many research and development works on Bi-2223 superconducting wires from fundamental aspects and the fabrication process to applications such as current leads, power cables, magnets, and motors. Especially, there are many daily operating apparatus incorporated with Bi-2223 superconducting wires due to their electro-magnetic, mechanical and thermal performance, and industrial productivity for long length wires with an affordable economic point of view.

The purpose of this book is to cover all aspects of Bi-2223 superconducting wires from fundamental research, and the fabrication process to applications. This book contains about 40 chapters written by distinguished experts in the world. Bi-2223 superconducting wires have possibilities to realize much higher performance than those of today. I really hope that this book could contribute to the future progress of oxide superconducting wires, including Bi-2223.

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Finally, I invited Dr. Hitoshi Maeda to write an invited preface for this book, and he accepted my invitation. Unfortunately, he passed away on May 24<sup>th</sup>, 2014. My invitation could not be realized. For his memory, I would like to show his handwritten memorandum on his discovery of BSCCO which he wrote on November 20<sup>th</sup>, 2003 on his visit to Tsinghua University (Courtesy of Professor Zhenghe Han).

Tried to isolate two phases for 20 days by 4 posens - not succeeded

1988.1.20 Paper Submission Press Presentation

Key of the Discovery

- ① Corristance of two alkaline-earths Ca+Sr
   not usual idea in those days
  Adjustment of Cu-Cu distance → Wrong idea
  → lead to big success
  · Cansual Discovery
- No information on High-Te results
  Almost new discovery not come from the existed results and theory
- 3 My characteristics
  not like to follow other persons
  If knew Bi 2201, not challenged for Bi Crides
- · New materials searching work Risky Lat exciting

Kenichi Sato Editor

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# PART 1 Research

### Chapter 1.1

# Materials Aspects of Bi-2223

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Among a large number of cuprate superconductors, Bi-2223 is one of the well-developed one as superconducting tapes because of its high  $T_{\rm c}$ , chemical stability and many other reasons. In this chapter, characteristic features of Bi-2223 are summarized and its superconducting properties as practical materials are compared with other superconductors. Furthermore, potentials of Bi-2223 materials are discussed from a viewpoint of controlling chemical composition.

#### 1. Introduction

The successive discoveries of cuprate superconductors with high critical temperature  $T_{\rm c}$  up to 135 K in 1986–1993 had opened possibility of applications of superconducting technologies at high temperatures, such as the boiling point of liquid nitrogen 77 K. Although metallic superconductors, such as Nb–Ti, Nb<sub>3</sub>Sn, and Nb, have been extensively used as wires, tapes, films, and other materials thus far, they are applicable only at very low temperatures, liquid helium temperature 4.2 K or lower, due to their low  $T_{\rm c}$ , which limited application fields of superconducting technologies. In particular, robust cryostats equipped with high performance heat-insulating layers have been always indispensable. Cuprate superconductors, however, have layered crystal structure composed of superconducting and blocking (=non-superconducting) layers, resulting in various

Table 1. High- $T_{\rm c}$  cuprate superconductors, which can be candidate materials applicable at 77 K.

System	Chemical Formula	Abbr.	$T_{c(\max)}$ [K]	$\gamma$	Crystal Shape
RE-based	$REBa_2Cu_3O_y$	RE123	96	$\sim 7$	block
	$RE_2Ba_4Cu_7O_y$	RE247	95		block, plate
	(RE,Ca) <sub>2</sub> Ba <sub>4</sub> Cu <sub>8</sub> O <sub>16</sub>	RE124	90		block
Bi-based	$\mathrm{Bi}_{2}\mathrm{Sr}_{2}\mathrm{Ca}_{n-1}\mathrm{Cu}_{n}\mathrm{O}_{y}$	Bi22(n-1)n	110	$\sim 100$	thin plate
	$(Bi,Pb)_2Sr_2Ca_{n-1}Cu_nO_y$	2	116	$\sim 50$	thin plate
Tl-based	$TlBa_2Ca_{n-1}Cu_nO_y$	Tl12(n-1)n	132		plate
	$\mathrm{Tl}_{2}\mathrm{Ba}_{2}\mathrm{Ca}_{n-1}\mathrm{Cu}_{n}\mathrm{O}_{y}$	Tl22(n-1)n	127	$\sim 80$	plate
Hg-based	$HgBa_2Ca_{n-1}Cu_nO_y$	Hg12(n-1)n	135	$\sim 80$	block
	$(\mathrm{Hg},\mathrm{Re})\mathrm{Ba}_{2}\mathrm{Ca}_{n-1}\mathrm{Cu}_{n}\mathrm{O}_{y}$		135	$\sim 30$	block

 $<sup>*\</sup>gamma$  values are typical values at carrier optimally-doped state.

anisotropic properties. Characteristic features of superconducting cuprates, which can be synthesized as sintered bulks by solid-state reaction under ambient pressure and/or below 1 MPa, with higher  $T_{\rm c}$  than 90 K are listed in Table 1.

For practical applications at higher temperature, Hg- and Tlbased superconductors are attractive because of their high  $T_{cs}$ . In fact, developments of superconducting materials had been attempted for these compounds for a decade after their discoveries. However, studies for developing these materials are almost stopped at the present stage, because any advantageous points were not found in critical current properties of their polycrystalline materials compared to those of RE- and Bi-based superconductors. This is partly due to containing highly volatile components at synthesis temperatures, Hg- or Tl-based superconductor, which is considered to deteriorate grain coupling, and poor cleavability, that will be mentioned later. Although, the Bi-based superconductors also contain volatile components, Bi and/or Pb, their equilibrium vapor pressures at synthesis temperature are much lower than those of Hg- and Tl-based superconductors. In addition, the Bi-based superconductors do not contain Ba, while it is included in other high- $T_c$  compounds. Impurity phases and grain boundaries of cuprate superconductors containing Ba as a constituent element are quite sensitive to moisture and