Editor-in-Chief

Guy Deutscher

**World Scientific Series**
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# Research, Fabrication and Applications of Bi-2223 HTS Wires

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*edited by Kenichi Sato*

*Forthcoming*

$MgB_2$ Superconducting Wires: Basics and Applications
*edited by René Flükiger*

*This book is dedicated to my wife Motoko, daughter Yuri, and son Takaaki.*

# 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$^{th}$ December, 1987 by Dr. Hitoshi Maeda, *et al.* There are three compounds in the BSCCO system, and Bi-2223 ($Bi_2Sr_2Ca_2Cu_3O_{10}$) 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.

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 $24^{th}$, 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 $20^{th}$, 2003 on his visit to Tsinghua University (Courtesy of Professor Zhenghe Han).

Tried to isolate two phases for 20 days by 4 persons
→ not succeeded

1988.1.20 Papr Submission
Press Presentation

Key of the Discovery

① Coexistence of two alkaline-earths Ca+Sr
- not usual idea in those days
Adjustment of Cu-Cu distance → Wrong idea
→ lead to big success
∘ Camsual Discovery

② No information on High-Tc results

Almost new discovery not come from the existed results and theory

③ My characteristics

not like to follow other persons
If knew Bi2201, not challenged for Bi Oxides

⊙ New materials searching work - Risky but exciting

Kenichi Sato
Editor

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PART 1

# Research

Chapter 1.1

# Materials Aspects of Bi-2223

Jun-ichi Shimoyama

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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 $T_c$, 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 $T_c$ 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, $Nb_3Sn$, 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 $T_c$, 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-$T_c$ 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 | ~7 | block |
| | $RE_2Ba_4Cu_7O_y$ | RE247 | 95 | | block, plate |
| | $(RE,Ca)_2Ba_4Cu_8O_{16}$ | RE124 | 90 | | block |
| Bi-based | $Bi_2Sr_2Ca_{n-1}Cu_nO_y$ | Bi22$(n-1)n$ | 110 | ~100 | thin plate |
| | $(Bi,Pb)_2Sr_2Ca_{n-1}Cu_nO_y$ | | 116 | ~50 | thin plate |
| Tl-based | $TlBa_2Ca_{n-1}Cu_nO_y$ | Tl12$(n-1)n$ | 132 | | plate |
| | $Tl_2Ba_2Ca_{n-1}Cu_nO_y$ | Tl22$(n-1)n$ | 127 | ~80 | plate |
| Hg-based | $HgBa_2Ca_{n-1}Cu_nO_y$ | Hg12$(n-1)n$ | 135 | ~80 | block |
| | $(Hg,Re)Ba_2Ca_{n-1}Cu_nO_y$ | | 135 | ~30 | block |

*$\gamma$ 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 $T_c$ than 90 K are listed in Table 1.

For practical applications at higher temperature, Hg- and Tl-based superconductors are attractive because of their high $T_c$s. 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