

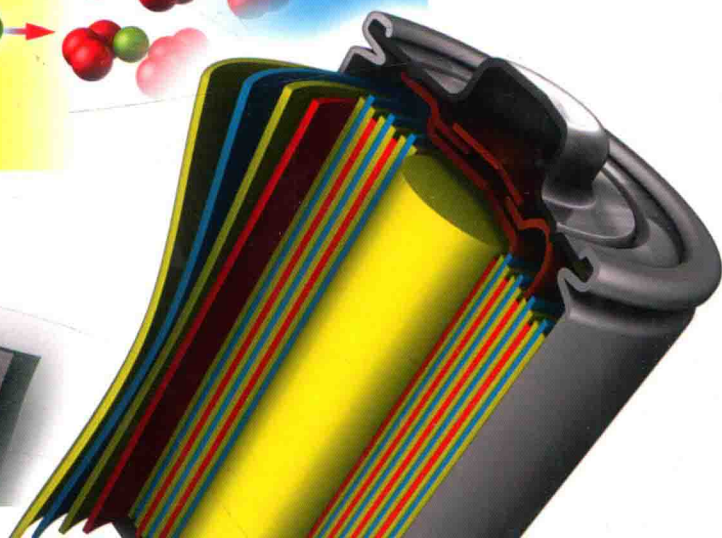
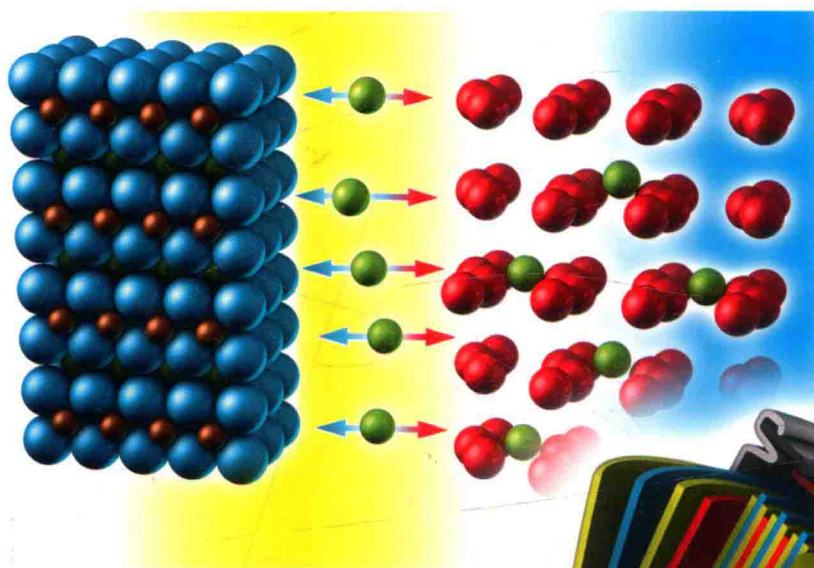
Claus Daniel and  
Jürgen O. Besenhard (Editors)

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# Handbook of Battery Materials

Second, Completely Revised and Enlarged Edition

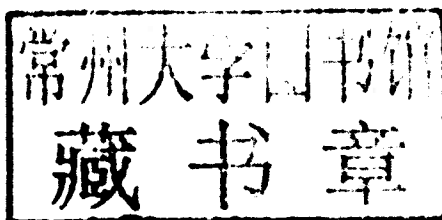
Volume 2



*Edited by Claus Daniel and Jürgen O. Besenhard*

## **Handbook of Battery Materials**

Second, Completely Revised and Enlarged Edition



WILEY-VCH Verlag GmbH & Co. KGaA

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**Handbook of Battery Materials**

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## Dedication: Jürgen O. Besenhard (1944–2006)

The first edition of the “Handbook of Battery Materials” was edited by Professor Jürgen Otto Besenhard. Jürgen Besenhard began his scientific career at the time, when the era of lithium batteries came up. With his strong background in chemistry and his outstanding ability to interpret and understand the complex phenomena behind the many exploratory research findings on lithium batteries in the late 1960s and early to mid 1970s, Jürgen Besenhard was able to attribute “performance” to material properties. His early work is evidence for this:

- 1) Understanding of reversible alkali metal ion intercalation into graphite anodes (*J. Electroanal. Chem.*, **53** (1974) 329 and *Carbon*, **14** (1976) 111)
- 2) Understanding of reversible alkali metal ion insertion into oxide materials for cathodes (*Mat. Res. Bull.*, **11** (1976) 83 and *J. Power Sources*, **1** (1976/1977) 267)
- 3) First reviews on lithium batteries (*J. Electroanal. Chem.*, **68** (1976) 1 and *J. Electroanal. Chem.*, **72** (1976) 1)
- 4) Preparation of lithium alloys with defined stoichiometry in organic electrolytes at ambient temperature (*Electrochim. Acta*, **20** (1975) 513).

Jürgen Besenhard’s research interests were almost unlimited. After he received a Full Professorship at the University of Münster (Germany) in 1986 and especially after 1993, when he assumed the position as head of the Institute of Chemistry and Technology at Graz University of Technology in Austria, he expanded his activities to countless topics in the field of applied electrochemistry. But his favorite topic, “his dedication,” has always been “Battery Materials.”

Jürgen Otto Besenhard was an exceptional and devoted scientist and he leaves behind an enduring record of achievements. He was considered as a leading authority in the field of lithium battery materials. His works will always assure him a highly prominent position in the history of battery technology.

Prof. Besenhard was also a highly respected teacher inside and outside the university. Consequently, it was only natural that he edited a book, which attempted to give explanations, rather than only summarizing figures and facts. The “Handbook of Battery Materials” was one of Jürgen Otto Besenhard’s favorite projects. He knew that materials are the key to batteries. It is the merit of Claus Daniel and the publisher Wiley, that this project will be continued.

May this new edition of the “Handbook of Battery Materials” be a useful guide into the complex and rapidly growing field of battery materials. Beyond that, it is my personal wish and hope that the readers of this book may also take the chance to review Prof. Besenhard’s work. Jürgen Otto Besenhard has been truly one of the fathers of lithium batteries and lithium ion batteries.

Münster, Germany, July, 2011

*Martin Winter*

## Preface to the Second Edition of the Handbook of Battery Materials

For Kijan and Stina

**The language of experiment is more authoritative than any reasoning, facts can destroy our ratiocination – not vice versa.**

Count Alessandro Volta, 1745–1827

Inventor of the Battery

You are looking at the second edition of the Handbook of Battery Materials. It has been 12 years since the first edition edited by Prof. Jürgen Besenhard was published.

This second edition is dedicated in memory of world renowned Prof. Jürgen Besenhard who was a pioneer in the field of electrochemical energy storage and lithium batteries. As a young scientist in the field of electrochemical energy storage, I am humbled to inherit this handbook from him.

Over the last decade, driven by consumer electronics, power tools, and recently automotive and renewable energy storage, electrochemical energy storage chemistries and devices have been developed at a never before seen pace. New chemistries have been discovered, and continued performance increases to established chemistries are under way. With these developments, we decided to update the handbook from 1999. The new edition is completely revised and expanded to almost double its original content.

Due to the fast pace of the market and very quick developments on large scale energy storage, we removed the chapter on *Global Competition*. It might be outdated by the time this book actually hits the shelves. Chapters from Parts I and II from the first edition on *Fundamentals and General Aspects of Electrochemical Energy Storage*, *Practical Batteries*, and *Materials for Aqueous Electrolyte Batteries* have been revised for the new edition to reflect the work in the past decade. Part III on *Materials for Alkali Metal Batteries* has been expanded in view of the many research efforts on lithium ion and other alkali metal ion batteries. In addition, we added new Parts IV on *New Emerging Technologies* and V on *Performance and Technology Development* with chapters on *Metal Air*, *Catalysts*, and *Membranes*, *Sulfur*, *System Level Modeling*, *Mechanics of Battery Materials*, and *Electrode Manufacturing*.



In our effort, we strongly held on to Prof. Besenhard's goal to "*fill the gap*" between fundamental electrochemistry and application of batteries in order to provide a "*comprehensive source of detailed information*" for "*graduate or higher level*" students and "*those who are doing research in the field of materials for energy storage.*"

I would like to thank all authors who contributed to this book; Craig Blue, Ray Boeman, and David Howell who made me apply my experience and knowledge from a different area to the field of electrochemical energy storage; and Nancy Dudley who continues to be a resourceful expert advisor to me.

Finally, I thank my wife Isabell and my family for the many sacrifices they make and support they give me in my daily work.

Oak Ridge, TN, July 2011

*Claus Daniel*

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