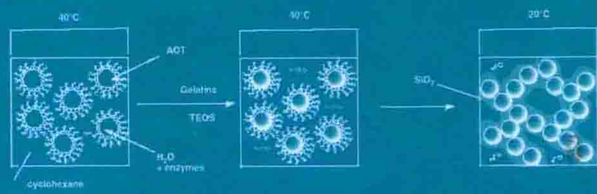
VOLUME I: SOL-GEL PROCESSING



VOLUME EDITOR: **HIROMITSU KOZUKA**

HANDBOOK OF SOL-GEL SCIENCE AND TECHNOLOGY

Processing Characterization and Applications

EDITOR Sumio Sakka

Kluwer Academic Publishers

HANDBOOK of SOL–GEL SCIENCE and TECHNOLOGY

Processing, Characterization and Applications

edited by

Sumio Sakka
Professor Emeritus of Kyoto University
Hirakata, Osaka, Japan

VOLUME I

SOL–GEL PROCESSING

Volume editor:

Hiromitsu Kozuka
Kansai University
Suita, Osaka, Japan

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VOLUME I

SOL–GEL PROCESSING

Preface to the Handbook (Sol–Gel Science and Technology)

This three-volume Handbook "Sol–Gel Science and Technology" was planned with the purpose of providing those who are interested in processing, characterization and application of materials with comprehensive knowledge on sol–gel science and technology.

Around 1970, three different groups in the field of inorganic materials published research results on preparation of glass and ceramics via solutions or sol–gel route. H. Dislich prepared a pyrex-type borosilicate glass lens by heating a compact of metal alkoxide derived powder at temperatures as low as 650°C. R. Roy prepared a millimeter-size small piece of silica glass via sol–gel route at temperatures around 1000°C. Mazdiyasni et al. showed that well-sintered, dense ferroelectric ceramics can be obtained at temperatures as low as 900°C, when sol–gel powders prepared from solutions of metal alkoxides are employed for sintering.

Those works stimulated people's interest in sol–gel preparation of inorganic materials, such as glasses and ceramics. Materials scientists and engineers paid attention to the possibility of this method in giving shaped materials directly from a solution without passing through the powder processing and the fact that the maximum temperature required for processing is very low compared with conventional technology for preparing glasses and ceramics. Thus, many efforts have been made in preparing bulk bodies, coating films, membranes, fibers and particles, and many commercial products were born.

The significant characteristics unique to the sol–gel method became evident, when organic-inorganic hybrid materials were prepared by H. Schmidt and silica materials containing functional organic molecules were prepared by Avnir in early 1980's. Such materials are produced at low temperatures near room temperature, where no decomposition of organic matter takes place. Low temperature synthesis and preparation of materials is the world of chemists. Therefore, the sol–gel method was propagated to the wide area including not only glasses and ceramics, but also organic and biomaterials.

In 1990, an excellent book entitled "Sol–Gel Science" was written by Brinker and Scherer, obtaining a very high reputation. However, the remarkable scientific and technological development and broadening in the sol–gel field, together with an enormous increase in sol–gel population, appeared to demand publication of a new, comprehensive Handbook on sol–gel science and technology.

Thus, it was planned to publish the present Handbook, which consists of the following three volumes:

Volume 1 Sol–Gel Processing
Volume editor: Prof. Hiromitsu Kozuka
Volume 2 Characterization and Properties of Sol–Gel Materials and Products
Volume editor: Prof. Rui M. Almeida
Volume 3 Applications of Sol–Gel Technology
Volume editor: Prof. Sumio Sakka

Volume 1 compiles the articles describing various aspects of sol–gel processing. Considering that the sol–gel method is a method for preparing materials, the knowledge on sol–gel processing is of primary importance to all those who are interested in sol–gel science and technology. Articles describing processing of some particular property as well as general basics for sol–gel processing are collected.

Volume 2 consists of the articles dealing with characterization and properties of sol–gel materials and products. Since materials exhibit their functional properties based on their microstructure, characterization of the structure is very important. We can produce useful materials only when processing-characterization-property relationships are worked out. This indicates the importance of the articles collected in Volume 2.

The title of Volume 3 is "Applications of Sol–Gel Technology". The sol–gel technology is one of the methods for producing materials and so there are many other competitive methods, whenever a particular material is planned to be produced. Therefore, for the development of this excellent technology, it is important to know the sol–gel science and technology in producing new materials as well as already achieved applications. This is the purpose of Volume 3.

Sol–gel technology is a versatile technology, making it possible to produce a wide variety of materials and to provide existing materials with novel properties. I hope this three-volume Handbook will serve as an indispensable reference book for researchers, engineers, manufacturers and students working in the field of materials.

Finally, I would like to express my sincere thanks to all the authors of the articles included in the Handbook for their efforts in writing excellent articles by spending their precious time. As general editor I extend my thanks to Prof. H. Kozuka and Prof. R. Almeida for their difficult work of editing each Volume. I have to confess that this Handbook would not have been realized without enthusiastic encouragement of Mr. Gregory Franklin, senior editor at Kluwer Academic Publishers.

Sumio Sakka

Preface to Volume 1 ("Sol–Gel Processing")

Volume 1 entitled "Sol–Gel Processing" has 27 chapters, concerning techniques for sol–gel processing of materials of specified shapes, structure, and chemistry, including chemistry of precursors and special processing techniques.

Sol–gel technology has already long history, starting with processing of oxide materials including glass and ceramics about 30 years ago. However, since then, the technology has been employed in preparation not only of oxides, but also of non-oxide materials including nitrides, carbides, fluorides, and sulfides as well as oxynitride and oxycarbide glasses. Processing of organic-inorganic materials is now a very active field of research, which has been expanded even in the field of biotechnology as is represented by research on encapsulation of enzymes, antibodies and bacteria.

The sol–gel technology started with processing of dense, bulk materials, and great efforts have been made on how to densify porous gels into glasses and ceramics. However, recently sol–gel processing of mesoporous and macroporous materials has also attracted much attention, including materials with well-controlled pore characteristics and highly porous materials, which have excellent chemical and photonic functions. As far as the shape of the products are concerned, powders and fibers are also important products via sol–gel processing, the techniques of which are still in progress. Thin films or coatings are other shaped materials that can be prepared by sol–gel method, which also has already long history. Although dip- and spin-coating methods are very familiar techniques, and science on sol–gel thin film deposition seems to have been established already, there are still technical issues to be solved scientifically for practical fabrication of industrial products. Deposition techniques have now a variety, such as ultrasonic pulverization of aerosols and electrophoretic deposition, and those allowing coating of plastic materials and self-standing thick films have also been developed. There are also special techniques like non-hydrolytic sol–gel technique, which produces unique materials, and UV irradiation that activates the chemical bonds of organic and inorganic components in sol–gel films.

Metal alkoxides are the most important precursors employed in sol–gel processing. The development of synthesis technique is often the key for preparing materials of excellent functions with sophisticated nanostructures. Then, how about other precursors than alkoxides? Sometimes people say that "sol–gel method" exclusively represents processing that undergoes hydrolysis and polycondensation of metal alkoxides, ending up with formation of metalloxane bonds. And also some people say that "sol" represents "colloidal solutions," not "polymer solutions." Prof. Pierre-Gilles de Gennes, who was awarded the Nobel Prize in Physics in 1991, wrote a famous book entitled "Scaling Concepts in Polymer Physics" (Cornel University Press, Ithaca, 1979). In that book, first he precisely describes theoretical aspects of "polymer solutions," which he never calls "sols." Then, he describes the conversion of "polymer solutions" into "gels," which he calls "sol–gel transition," however. No other terms than "sol–gel transition" can represent this kind of conversion, and we should recognize that "sol–gel method" is a processing that passes through "sol–gel transition" irrespective of the kinds of precursors. Science and technology have been greatly developed on (i) metal salt routes for thin film deposition, (ii) polymeric gel precursors for materials with high homogeneity, and (iii) aqueous precursors ideal for material production in industries.

The current state of science and technology on all of these are covered in Volume 1, and the chapters are grouped in eight parts; (1) Sol–gel precursors, (2) Processing of powders and bulk materials, (3) Processing of non-oxide materials, (4) Processing of thin films, (5) Processing of fibers and monodisperse perticles, (6) Encapsulation of organic materials, (7) Processing of catalysts, porous materials and aerogels, and (8) Special techniques used in sol–gel processing. Each chapter has been written by a leading expert in the field. I hope that Volume 1 will provide great information on the current state of sol–gel processing of materials of specified shapes, structure, and chemistry, including chemistry of precursors and special processing techniques.

Finally I would like to thank all the authors for spending their precious time, and making much efforts to make great contribution to the Handbook. I also thank Mr. Gregory Granklin, senior editor in Kluwer Academic Publishers and Prof. Sumio Sakka for continuous encouragement.

Hiromitsu Kozuka

LIST OF CONTRIBUTORS

VOLUME I

Vadim G. Kessler
Department of Chemistry, SLU
Uppsala
Sweden

Kazumi Kato
National Institute of Advanced Industrial Science and Technology
Nagoya
Japan

Keishi Nishio
Department of Materials Science and Technology
Faculty of Industrial Science and Technology
Tokyo University of Science
Noda, Chiba
Japan

Toshio Tsuchiya
Department of Materials Science and Technology
Faculty of Industrial Science and Technology
Tokyo University of Science
Noda, Chiba
Japan

Valery Petrykin
Institute of Multidisciplinary Research for Advanced Materials
Tohoku University
Sendai
Japan

Masato Kakihana
Institute of Multidisciplinary Research for Advanced Materials
Tohoku University
Sendai
Japan

Yutaka Ohya
Department of Materials Science and Technology
Faculty of Engineering
Gifu University
Gifu
Japan

Sumio Sakka
Professor Emeritus of Kyoto University
Hirakata, Osaka
Japan

Dibyendu Ganguli
Indian Association for the Cultivation of Science
Kolkata
India

Kanichi Kamiya
Department of Chemistry for Materials
Faculty of Engineering
Mie University
Tsu, Mie
Japan

Shinobu Fujihara
Department of Applied Chemistry
Faculty of Science and Technology
Keio University
Yokohama
Japan

Rui M. Almeida
Department of Materials Engineering
Instituto Superior Técnico
Lisboa
Portugal

Jian Xu
Department of Materials Engineering
Instituto Superior Técnico

Lisboa
Portugal
and
Department of Chemistry and Physics
Nottingham Trent University
Nottingham
United Kingdom

Hiromitsu Kozuka
Kansai University
Materials Science and Engineering
Suita, Osaka
Japan

Michel Langlet
Laboratoire des Matériaux et du Génie Physique
Institut National Polytechnique de Grenoble
Domaine Universitaire de Saint Martin d'Hères
France

Atsunori Matsuda
Department of Materials Science
Toyohashi University of Technology
Toyohashi, Aichi
Japan

Masahiro Tatsumisago
Department of Applied Materials Science
Graduate School of Engineering
Osaka Prefecture University
Sakai, Osaka
Japan

Masayuki Yamane
Emeritus Professor
Tokyo Institute of Technology
Yokohama
Japan

Shin-ichi Hirano
Department of Applied Chemistry
Graduate School of Engineering
Nagoya University
Nagoya
Japan

Wataru Sakamoto
EcoTopia Science Institute
Nagoya University
Nagoya
Japan

Subramanian Ramakrishnan
Department of Chemical and Biomolecular Engineering
University of Illinois
Urbana, Illinois
USA

Charles F. Zukoski
Department of Chemical and Biomolecular Engineering
University of Illinois
Urbana, Illinois
USA

Kazunori Matsui
Department of Applied Material and Life Science
College of Engineering
Kanto Gakuin University
Yokohama
Japan

Jacques Livage
Laboratoire de Chimie de la Matière Condensée
Université Pierre et Marie Curie
Paris
France

Thibaud Coradin
Laboratoire de Chimie de la Matière Condensée
Université Pierre et Marie Curie
Paris
France

Akifumi Ueno
Department of Materials Science
Shizuoka University
Hamamatsu, Shizuoka
Japan

Kazuki Nakanishi
Department of Material Chemistry
Graduate School of Engineering

Kyoto University
Kyoto
Japan

Karen J. Edler
Department of Chemistry
University of Bath
Bath
United Kingdom

Jean Phalippou
Laboratoire des verres
Université de Montpellier II
Montpellier
France

Thierry Woignier
Laboratoire des verres
Université de Montpellier II
Montpellier
France

Florence Despetis
Laboratoire des verres
Université de Montpellier II
Montpellier
France

Sylvie Calas
Laboratoire des verres
Université de Montpellier II
Montpellier
France

André Vioux
Laboratoire de Chimie Moleculaire et Organisation de Solide
Université de Montpellier 2
Place Eugene Bataillon
France

Pierre Hubert Mutin
Laboratoire de Chimie Moleculaire et Organisation de Solide
Université de Montpellier 2
Place Eugene Bataillon
France

Hiroaki Imai
Department of Applied Chemistry
Faculty of Science and Technology
Keio University
Yokohama
Japan

VOLUME II

Kanichi Kamiya
Department of Chemistry for Materials
Faculty of Engineering
Mie University
Tsu, Mie
Japan

Francesco d' Acapito
Istituto Nazionale per la Fisica della Materia
OGG—European Synchrotron Radiation Facility
Grenoble
France

Mark E. Smith
Department of Physics
University of Warwick
Coventry
United Kingdom

Diane Holland
Department of Physics
University of Warwick
Coventry CV4 7AL
United Kingdom

Rui M. Almeida
Department of Materials Engineering
Instituto Superior Técnico
Lisboa
Portugal

Ana C. Marques
Department of Materials Engineering
Instituto Superior Técnico
Lisboa
Portugal

Maurizio Montagna
Department of Physics
University of Trento

Povo
Italy

Diane Holland
Department of Physics
University of Warwick
Coventry CV4 7AL
United Kingdom

Plinio Innocenzi
Dipartimento di Architettura e Pianificazione
Laboratorio di Scienza dei Materiali e Nanotecnologie
Università di Sassari
Alghero (SS)
Italy

Giovanna Brusatin
Dipartimento di Ingegneria Meccanica
Università di Padova
Padova
Italy

Massimo Gugliemi
Dipartimento di Ingegneria Meccanica
Università di Padova
Padova
Italy

Florence Babonneau
Chimie de la Matiere Condensee
Université de Paris
Paris
France

Aldo F. Craievich
Institute of Physics
University of Sao Paulo
Sao Paulo
Brazil

Kazuki Nakanishi
Department of Materials Chemistry
Graduate School of Engineering
Kyoto University
Kyoto
Japan

Kiyoharu Tadanaga
Department of Applied Materials Science
Graduate School of Engineering
Osaka Prefecture University
Sakai, Osaka
Japan

Tsutomu Minami
Department of Applied Materials Science
Graduate School of Engineering
Osaka Prefecture University
Sakai, Osaka
Japan

René Pirard
Université de Liege
Laboratoire de Genie Chimique
Institut de Chimie
Liege
Belgium

Christelle Alié
Université de Liege
Laboratoire de Genie Chimique
Institut de Chimie
Liege
Belgium

Jean-Paul Pirard
Université de Liege
Laboratoire de Genie Chimique
Institut de Chimie
Liege
Belgium

Sumio Sakka
Professor Emeritus of Kyoto University
Hirakata, Osaka
Japan

Hiroshi Yokogawa
Coating Business Promotion Group
Matsushita Electric Works, Ltd.
Kadoma, Osaka
Japan

T. Woignier
Laboratoire des Verres
Université de Montpellier II

Montpellier
France

Jean Phalippou
Laboratoire des verres
Université de Montpellier II
Montpellier
France

F. Despetis
Laboratoire des Verres
Université de Montpellier II
Montpellier
France

P. Etienne
Laboratoire des verres
Université de Montpellier II
Montpellier
France

A. Alaoui
Laboratoire des verres
Université de Montpellier II
Montpellier
France

L. Duffours
Laboratoire des verres
Université de Montpellier II
Montpellier
France

Michel A. Aegerter
Leibniz-Institut fuer Neue Materialien gem. GmbH (INM)
Saarbruecken
Germany

John D. Mackenzie
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

Eric P. Bescher
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

Giancarlo C. Righini
Optoelectronics and Photonics Department
Nello Carrara Institute of Applied Physics
CNR-National Research Council
Firenze
Italy

Eric Yeatman
Department of Electrical and Electronic Engineering
Imperial College of Science, Technology and Medicine
London
United Kingdom

Maurizio Ferrari
CNR-IFN, Istituto di Fotonica e Nanotechnologie
CSMFO Group
Povo-Trento
Italy

Hiroyuki Nasu
Department of Chemistry for Materials
Faculty of Engineering
Mie University Kamihama
Tsu, Mie
Japan

Feng Liu
Departments of Chemistry and Materials Science and Engineering
Johns Hopkins University
Baltimore, Maryland
USA

Mei Yang
Departments of Chemistry and Materials Science and Engineering
Johns Hopkins University
Baltimore, Maryland
USA

Gerald J. Meyer
Departments of Chemistry and Materials Science and Engineering

Johns Hopkins University
Baltimore, Maryland
USA

Yuhuan Xu
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

John D. Mackenzie
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

Joerg Puetz
Leibniz-Institut fuer Neue
Materialien gem. GmbH (INM)
Saarbruecken
Germany

Sabine Heusing
Leibniz-Institut fuer Neue
Materialien gem. GmbH (INM)
Saarbruecken
Germany

Michel A. Aegerter
Leibniz-Institut fuer Neue Materialien gem. GmbH (INM)
Saarbruecken
Germany

VOLUME III

Sumio Sakka
Professor Emeritus of Kyoto University
Hirakata, Osaka
Japan

Dennis J. Trevor
OFS Laboratories
Murray Hill, New Jersey
USA

Kazuki Nakanishi
Department of Material Chemistry
Graduate School of Engineering
Kyoto University
Kyoto
Japan

Hiroshi Yokogawa
Coating Business Promotion Group
Matsushita Electric Works, Ltd.
Kadoma, Osaka
Japan

Jean Phalippou
Laboratoire des verres
Université de Montpellier II
Montpellier
France

P. Dieudonne
Laboratoire des verres
Universite de Montpellier II
Montpellier
France

A. Faivre
Laboratoire des verres
Universite de Montpellier II
Montpellier
France

T. Woignier
Laboratoire des Verres
Université de Montpellier II
Montpellier
France

P. Sujatha Devi
Central Glass and Ceramic Research Institute
Kolkata
India

Dibyendu Ganguli
Indian Association for the Cultivation of Science
Kolkata
India

Christian Guizard
Institut Europeen de Membranes
Montpellier
France

Andre Ayral
Institut Europeen de Membranes
Montpellier
France

Mihai Barboiu
Institut Europeen de Membranes
Montpellier
France

Anne Julbe
Institut Europeen de Membranes
Montpellier
France

Tatsuhiko Adachi
Ube-Nitto Kasei Co., Ltd.
Gifu
Japan

Thomas E. Wood
3M Company
St. Paul, Minnesota
USA

Dwight D. Erickson
3M Company
St. Paul, Minnesota
USA

Mark G. Schwabel
3M Company
St. Paul, Minnesota
USA

Chris J. Goodbrake
3M Company
St. Paul, Minnesota
USA

Kanichi Kamiya
Department of Chemistry for Materials
Faculty of Engineering
Mie University
Tsu, Mie
Japan

Masayuki Nogami
Department of Materials Science and Engineering
Nagoya Institute of Technology
Nagoya
Japan

Renata Reisfeld
Department of Chemistry
Hebrew University
Jerusalem
Israel

Makoto Kuwabara
Interdisciplinary Graduate School of Engineering Science
Kyushu University
Kasuga, Fukuoka
Japan

Michael Graetzel
Laboratory of Photonics and Interfaces
Swiss Federal Institute of Technology
Lausanne
Switzerland

Lisa C. Klein
Rutgers University
Ceramic & Materials Engineering
Piscataway, New Jersey
USA

Mario Aparacio
Consejo Superior de Investigaciones Cientificas
Instituto de Ceramica y Vidrio
Campus de Cantoblanco
Madrid
Spain

Francoise Damay
Laboratoire Leon Brillouin
Gif-sur-Yvette
France

Ovadia Lev
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

D. Rizkov
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

S. Mizrahi
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

I. Ekeltchik
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

Z. G. Kipervaser
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

V. Gitis
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

A. Goifman
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

A. Kamyshny, Jr.
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

A. D. Modestov
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

J. Gun
The Casali Institute of Applied Chemistry
The Chemistry Institute
The Hebrew University of Jerusalem
Jerusalem
Israel

Naoya Yoshida
Research Center for Advanced Science
and Technology
The University of Tokyo
Tokyo
Japan

Toshiya Watanabe
Research Center for Advanced Science
and Technology
The University of Tokyo
Tokyo
Japan

Hirokazu Tanaka
Nippon Sheet Glass Co., Ltd.
Ichihara, Chiba
Japan

Shigeki Obana
Nippon Sheet Glass Co., Ltd.
Ichihara, Chiba
Japan

Alicia Duran
Instituto de Ceramica y Vidrio (CSIC)
Campus de Cantoblanco
Madrid
Spain

Yolanda Castro
Instituto de Ceramica y Vidrio (CSIC)
Campus de Cantoblanco
Madrid
Spain

Ana Conde
Centro Nacional de Investigaciones Metalurgicas (CSIC)
Madrid
Spain

Juan José de Damborenea
Centro Nacional de Investigaciones Metalurgicas (CSIC)
Madrid
Spain

Koichi Takahama
Matsushita Electric Works
Kadoma, Osaka
Japan

S. Amberg-Schwab
Fraunhofer-Institut fur Silicatforschung
Wuerzburg
Germany

Eric P. Bescher
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

John D. Mackenzie
Department of Materials Science and Engineering
University of California, Los Angeles
California, USA

Plinio Innocenzi
Dipartimento di Architettura e Pianificazione
Laboratorio di Scienza dei Materiali e Nanotecnologie
Università di Sassari
Alghero (SS)
Italy

Jochanan Blum
Institute of Chemistry
The Hebrew University of Jerusalem
Jerusalem
Israel

David Avnir
Institute of Chemistry
The Hebrew University of Jerusalem
Jerusalem
Israel

Akiyoshi Osaka
Department of Bioscience and Biotechnology
Faculty of Engineering
Okayama University
Okayama
Japan

Kanji Tsuru
Department of Bioscience and Biotechnology
Faculty of Engineering
Okayama University
Okayama
Japan

Satoshi Hayakawa
Department of Bioscience and Biotechnology
Faculty of Engineering
Okayama University
Okayama
Japan

Caner Durucan
Department of Materials Science and Engineering
Materials Research Institute
The Pennsylvania State University
University Park, Pennsylvania
USA

Carlo G. Pantano
Department of Materials Science and Engineering
Materials Research Institute
The Pennsylvania State University
University Park, Pennsylvania
USA

Shiro Saka
Department of Socio-Environmental Energy Science
Graduate School of Energy Science