Chemical Sensor Technology

Vol.4

Edited by
Shigeru YAMAUCHI
National Rehabilitation Center for the Disabled, Tokorozawa, Japan

KODANSHA LTD. 1992
Tokyo

ELSEVIER
Amsterdam – London – New York – Tokyo

Chemical Sensor Technology

Vol.4

Edited by

Shigeru YAMAUCHI

Director, Rehabilitation Engineering Division, Research Institute, National Rehabilitation Center for the Disabled, Tokorozawa, Japan

KODANSHA LTD. 1992 **ELSEVIER**

Tokyo **Amsterdam—London—New York—Tokyo**

Copublished by
KODANSHA LTD., Tokyo
and
ELSEVIER SCIENCE PUBLISHERS B.V., Amsterdam

exclusive sales rights in Japan
KODANSHA LTD.
12–21, Otowa 2-chome, Bunkyo-ku, Tokyo 112, Japan

for the U.S.A. and Canada
ELSEVIER SCIENCE PUBLISHING COMPANY, INC.
655 Avenue of the Americas, New York, NY 10010, U.S.A.

for the rest of the world
ELSEVIER SCIENCE PUBLISHERS B.V.
25 Sara Burgerhartstraat, P.O. Box 211, 1000 AE Amsterdam, The Netherlands

ISBN 0-444-98680-4 (Elsevier)
ISBN 4-06-205458-2 (Japan)

Printed in Japan

Chemical Sensor Technology

Vol.4

Editorial Board

The board is composed of approximately 10 members, selected internationally. The editor(s) will be selected from the Japanese members and may change from year to year, depending on the topic of focus.

The role of each editorial board member is envisaged as making the book and its aims known, advising the chief editor(s) on their special fields and on general policy, and providing feedback on the standards, style and impact of the volume.

List of Contributors

ARAI, T. (241) National Defense Medical College, 3-2 Namiki, Tokorozawa 359, Japan

BARBI, G.B. (99) Institute for Advanced Materials, Joint Research Centre of the European Communities, 21020 Ispra (VA), Italy

BASTIAANS, G.J. (181) Institute for Physical Research and Technology, Iowa State University, Ames, Iowa 50011, U.S.A.

BOUSSE, L. (145) Molecular Devices Corporation, 4700 Bohannon Drive, Menlo Park, CA 94025, U.S.A.

CHIBA, A. (1) Figaro Engineering Inc., 1-5-3, Senba-nishi, Minoo, Osaka 562, Japan

CLECHET, P. (205) Interfacial Physicochemistry Laboratory (URA CNRS 404), Ecole Centrale de Lyon, B.P. 163, 69131-Ecully Cedex, France

FABRY, P. (111) Laboratoire d'Ionique et d'Electrochimie des Solides de Grenoble, ENSEEG/INPG, B.P.75, 38402 Saint-Martin-d'Hères Cedex, France

FUTATA, H. (85) Yazaki Meter Company Ltd., 23 Minamikashima, Futamata, Tenryu, Shizuoka 431-33, Japan

HEINEMAN, W.R. (125) Edison Sensor Technology Center, Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221-0172, U.S.A.

HUBER, E.W. (125) Marion Merrell Dow Research Institute, 2110 E. Galbraith Road, Cincinnati, Ohio 45215, U.S.A.

IWAMOTO, M. (63) Catalysis Research Center, Hokkaido University, Nishi 10, Kita 11, Kita-ku, Sapporo 060, Japan

JAFFREZIC-RENAULT, N. (205) Interfacial Physicochemistry Laboratory (URA CNRS 404) Ecole Centrale de Lyon, B.P. 163, 69131-Ecully Cedex, France

KIKUCHI, M. (241) National Defense Medical College, 3-2 Namiki, Tokorozawa 359, Japan

KURIYAMA, T. (241) Microelectronics Research Laboratories, NEC Corporation, 1120, Shimokuzawa, Sagamihara 229, Japan

KATSUBE, T. (225) Department of Information and Computer Science, Faculty of Engineering, Saitama Univeristy, 255 Shimo-Okubo, Urawa, Saitama 338, Japan

KIMURA, J. (241) Resources and Environmental Protection Research Laboratories, NEC Corporation, 4-1-1 Miyazaki, Miyamae-ku, Kawasaki 213, Japan

MARI, C.M. (99) Univeristy of Milan, Department of Physical Chemistry and Electrochemistry, Via Golgi 19, 20133 Milan, Italy

MARTELET, C. (205) Interfacial Physicochemistry Laboratory (URA CNRS 404), Ecole Centrale de Lyon, B.P. 163, 69131-Ecully Cedex, France

MATSUOKA, H. (253) Department of Biotechnology, Faculty of Technology, Tokyo University of Agriculture and Technology, 2-24-16 Nakamachi, Koganei, Tokyo 184, Japan

MIURA, N. (19) Department of Materials Science and Technology, Graduate School of Engineering Sciences, Kyushu University 39, 6-1, Kasugakouen, Kasuga, Fukuoka 816, Japan

MIZUTANI, F. (167) Research Institute for Polymers and Textiles, 1-1-4 Higashi, Tsukuba, Ibaraki 305, Japan

MOKWA, W. (43) Fraunhofer Institute of Microelectronic Circuits and Systems, Finkenstrasse 61, D-4100 Duisburg, Germany

OWICKI, J.C. (145) Molecular Devices Corporation, 4700 Bohannon Drive, Menlo Park, CA 94025, U.S.A.

PARCE, J.W. (145) Molecular Devices Corporation, 4700 Bohannon Drive, Menlo Park, CA 94025, U.S.A.

RAUEN, K.L. (125) Edison Sensor Technology Center, Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221-0172, U.S.A.

SIEBERT, E. (111) Laboratoire d'Ionique et d'Electrochimie des Solides de Grenoble, ENSEEG/INPG, B.P.75, 38402 Saint-Martin-d'Hères Cedex, France

TIEMAN, R.S. (125) Edison Sensor Technology Center, Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221-0172, U.S.A.

UCHIDA, H. (225) Department of Information and Computer Science, Faculty of Engineering, Saitama University, 255 Shimo-Okubo, Urawa, Saitama 338, Japan

YABUKI, S. (167) Research Institute for Polymers and Textiles, 1-1-4 Higashi, Tsukuba, Ibaraki 305, Japan

YAMAZOE, N. (19) Department of Materials Science and Technology, Graduate School of Engineering Sciences, Kyushu University 39, 6-1, Kasugakouen, Kasuga, Fukuoka 816, Japan

Preface

Research activity on chemical sensors is now flourishing throughout the world. Many papers on chemical sensors are being published in journals and read at domestic and international conferences. They convince us that *chemical sensors are here to stay*. When Prof. Seiyama organized the *Sensor Research Group* within the Electrochemical Society of Japan in 1977, *sensor* was not a popular term. Now, topics on sensors appear in newspapers, weekly magazines, and even on TV. This represents general acceptance and recognition that sensors are an indispensable element in modern society.

In the fourth volume of this series we have compiled state-of-the-art review papers on new principles, new devices, and detailed mechanism of various chemical sensors. They will help readers gain further understanding of devices in their own work and widen their scope in related areas concerning chemical sensors.

One strategic field of chemical sensors is biosensing for medical and health care equipment, especially useful in geriatric medicine. Frequent health checks at one's own home will be more and more necessary to keep the elderly healthy and active as the proportion of the aged in the population steadily increases all over the world. In some cases health conditions will have to be monitored constantly to give warnings or provide emergency assistance at the right time. Sensors discussed to date for this kind of application are mainly physical sensors for position, temperature, pressure sensing, or electrocardiography. Because biochemical substances play major roles in physiological processes such as metabolism, excitation and contraction of skeletal muscle and neurotransmission chemical sensing of the related biochemical substances will eventually become indispensable. From this point of view more than half the papers in this volume are relevant to biosensing. It is hoped that the reviews on biosensing will be beneficial to the future development of this kind of device.

Although various kinds of new devices and principles have been proposed not all of them have been commercially successful. Even scientifically fascinating and well-engineered devices sometimes find difficulty in the commercial market. Some of these encounter problems in the fact that reasonable production cost is required for a successful device, not just high performance. Moreover, new devices must be introduced at the right time to meet social needs. In this respect, I believe it is still instructive to read the legendary story of success in the development of the Taguchi gas sensor.

I wish to acknowledge the efforts of all the contributors who have prepared

manuscripts and the editorial board members who have given valuable advice. I would also like to express my sincere thanks to Mr. Ippei Ohta and other staff members of Kodansha Scientific Ltd. who have worked on this volume.

Shigeru YAMAUCHI
Editor
September 1991

Contents

Development of the TGS Gas Sensor

AKIRA CHIBA

Figaro Engineering Inc. 1-5-3, Senba-nishi, Minoo, Osaka 562, Japan

1. INTRODUCTION

The semiconductor-type gas sensor was first put to practical use in 1968 as a sensor for domestic gas leak detectors. This was the Figaro TGS (Taguchi Gas Sensor).

Naoyoshi Taguchi (former chairman of Figaro Engineering Inc.) began working on this sensor in 1962 and achieved success after six years of total dedication to the project. He and the present author then established Figaro Engineering Inc. and became first in the world to put the sensor to practical use.

This semiconductor-type gas sensor was first utilized in the field of domestic gas leak detectors thanks to its advantages of high sensitivity, high reliability, etc. At a later stage, this sensor was applied to detect alcohol content in drivers suspected of driving under the influence, to detect incomplete combustion in boilers, as auto-cooking sensors for microwave ovens, etc.

Unusual in Japan, Taguchi is a self-employed inventor and this invention was achieved completely on his own. Much of the recent high technology that has appeared as a result of systematic research contrasts strikingly to the humble origins of Taguchi's early achievements.

I wish to dedicate this report to Naoyoshi Taguchi for his achievement in developing the TGS after a long arduous road to acceptance, resulting finally in its being put to practical use by Figaro Engineering Inc.

2. INVENTION OF THE GAS SENSOR

2.1 Brief Personal History Prior to the Invention

Naoyoshi Taguchi was born in Kobe, Japan, in 1936. Taguchi has been my friend since elementary school and even then he was already full of curiosity and had a keen sense of observation. Whenever he went to a hilly area near his house, his pockets would be full of fossils, insects such as ant lions, stones and rocks that he had gathered on his way. Whenever he went to town, he would collect electric wires, tools, electric parts used in radios, motors, and generators in a junkshop and come back with his bicycle loaded full of junk. Whenever he visited a fireworks display, he used to run around collecting