Chapter 1

Introductory Chapter: Electrochemical Sensors Technology

Mohammed Muzibur Rahman and
Abdullah Mohamed Asiri

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68709

This book describes a comprehensive overview of electro-chemical sensors and biosensors for the analyses, investigation, and monitoring of the most significant unsafe analytes in the ecological as well as environmental field in industry, in treatment plants, and in environmental research. The contributed chapters stretch the reader a comprehensive study, state-of-the-art picture of the field of electro-chemical sensors or biosensors appropriate to environmental analytes, from the theoretical principles of their design to their implementation, realization, and potential application. It covers the most recent techniques and nanocomposites/nanomaterials for the preparation, construction, validation, analyses, and design of electro-chemical sensors/biosensors for bio-analytical, clinical, and environmental applications—emphasizing the latest classes of selective, sensitive, robust, fast response, stable, electro-chemical sensors as well as electrochemical biosensors for in vivo/vitro diagnosis.

Development in advanced nanotechnology and the conservatory of innovative chemical sensors, biosensors, ionic sensors with various composites/materials and nanodevices has been a regulating key task in the fabrication and improvement of very precise, perceptive, accurate, sophisticated, sensitive, and consistent efficient chemical sensors [1–3]. The exploration for even tiny electrodes accomplished in nano-level imaging and controlling of doped nanomaterials, doping agents (host-guest), biological, chemical, pathological samples, and chemical sensors has recently extended the attention of awareness of the scientist, mainly for control monitoring, owing to the amplifying essential for environmental safety and health monitoring [4–6]. Recently, great attention is provided for the detection of various unsafe, carcinogenic, toxic, hazardous chemicals, or biomolecules to live safely and as well as to prevent the ecological system from harmful effects of toxins [7–9].

Ronkainen et al. describe the enzyme-based electrochemical glutamate biosensor development, which has been proposed to play a significant role in various neurological and psychiatric disorders. In this contribution, the design, construction, and optimization of enzyme-based electrochemical biosensors for in vivo and in vitro detection of glutamate were discussed in this contribution [10–17]. Various glutamate biosensors have been discussed, including the developed glutamate monitoring dynamic levels of extracellular glutamate in the living brain tissue adding to the current medical knowledge of these complex neurotransmitter systems and ultimately impacting treatment plans [18–21]. More significantly, glutamate biosensors have been used in environmental monitoring, in the fermentation industry, and in the food industry for determination of Monosodium glutamate (MSG), a common flavor-enhancing food additive. With continuous developments in molecular biology, nanofabrication methods, immobilization methods of biomolecules and multiplexing capabilities, the production of sensitive, selective, fast, and easy-to-use biosensors for quantification of glutamate, and other neurotransmitters will be feasible in the not too distant future.

Qijin et al. approached some graphene paper-based electro-chemical sensors to illustrate recent advances in the research and development of 2D graphene papers as new and noble materials for electro-chemical sensors. It covers the design, fabrication, functionalization, and application evaluation of graphene papers. Precise monitoring of chemical or biological processes is of extreme importance for medical and biological applications. Electro-chemical sensors can ideally fulfill that goal by converting a chemical or biological response into a processable and quantifiable signal. In the past two decades, intensive research and development of electro-chemical sensors have enabled to fabricate different types of devices [22–31]. After the development of many successful commercial electro-chemical sensors in the classic configurations, currently, there is a notable transition and increasing demands for the development of flexible and wearable sensors. The development of flexible electro-chemical sensors depends crucially on the discovery and preparation of freestanding and flexible new materials. They first summarized the mainstream methods for fabrication of graphene papers/membranes with the focus on chemical vapor deposition techniques and solution-processing assembly. A large portion of this work is devoted to the highlights of specific functionalization of graphene papers with polymer and nanoscale functional building blocks for electrochemical sensing purposes. In terms of electrochemical sensing applications, the emphasis is on enzyme-graphene and nanoparticle-graphene paper-based systems for detection of glucose. We conclude this chapter with brief remarks and an outlook. In short, worldwide researchers have explored graphene paper–based sensors by exploiting their unique advantages including high sensitivity, conductivity, and in-situ sensing. The recent research advances suggest that graphene paper-based materials could play a significant role in developing flexible sensors and electronic devices due to their intriguing structural and functional features.

Murray et al. focused on managing H_2O cross-sensitivity using composite electrolyte "NO_x sensors". They approached NO_x sensors composed of PSZ, FSZ, and PSZ–FSZ composite electrolytes which were investigated using impedance spectroscopy under dry and humidified gas conditions. The microstructural properties, NO_x sensitivity, oxygen partial pressure and temperature dependence, as well as the response time of the sensors composed of the various electrolytes were characterized in order to interpret the electrochemical response with respect to water cross-sensitivity. In this approach, impedance spectroscopy was used to interpret the electrochemical response of NO_x sensors composed of PSZ, FSZ, and PSZ–FSZ composite electrolytes during operation under dry and humidified gas conditions. Analysis of the electrochemical responses of the 50PSZ–50FSZ-based sensors indicated PSZ contributed to lower water cross-sensitivity, while FSZ promoted NO_x sensitivity. Finally, sensors composed of the 50PSZ–50FSZ composite electrolyte demonstrated significant sensitivity to NO and low cross-sensitivity to water with negligible temperature dependence [32–35].

Lutic et al. describe electro-chemical sensors for monitoring indoor and outdoor air pollution. They approached a comprehensive presentation of the most common electro-chemical sensors used in real monitoring applications of air purity testing. The air quality monitoring stations based on electro-chemical sensors are nowadays used to determine the global pollution index of the atmospheric air, in order to prevent the risks toward human health and damage of environment, especially in the highly populated and industrialized urban areas. The electro-chemical gas sensors are nowadays indispensable in the monitoring of the atmosphere quality, especially due to pollutants associated with human activities. Carbon monoxide, sulfur oxides, hydrogen sulfide, and nitrogen oxides are only a few of species which can seriously damage the environment equilibrium by smog formation, acid rain, soil deterioration, water contamination as well as some direct damages on the human health [36–38]. The electrochemical gas sensing is based on gas oxidation or reducing reactions on sensing surfaces with catalytic potential, surfaces which suffer noticeable charge changes, that can be amplified and processed in order to generate a signal. The electro-chemical sensors are fast, reliable, small and cheap; therefore, their use covers nowadays the exhaust systems from automotives, domestic/residential gas detection, and leak checkers. Respecting the rated voltage as said by the manufacturer, using the sensor in the right temperature range, avoiding the deterioration due to exposure to humidity, avoiding contamination with various chemicals, lack of sudden exposure to extreme temperatures, and avoiding the mechanical shocks are basic conditions to preserve their work function and accuracy.

Lee et al. have focused on fabrication and characteristics of metal-loaded mixed metal oxides gas sensors for the detection of toxic gases for environmental purposes. They approached developing gas sensors which permit individuals to circumvent poisonous gases that may be produced in spaces with residues of inorganic/organic waste with certain temperature at 50°C or above. The response, sensitivity, and selectivity of these gas sensors to types of carcinogenic gases such as H_2S, toluene, and aldehyde were examined. The thick-film semiconductor sensors that detect some toxic gases were fabricated using nano-sized sensing materials powder (SnO_2, WO_3, and ZnO), and these were prepared via sol-gel and precipitation methods. Response to various lethal gases was measured and is defined as the ratio (Ra/Rg) of the resistance of the sensor film in air to the resistance of the film in toxic gas. Generally, semiconductor metal-oxide gas sensors can be used for diverse applications, ranging from equipment to monitor environmental and occupational safety to facilitating quality assurance through novel measurement. The nature of the gas-sensitive material and the concentration of the target gas (usually a few ppb~ppm) determine the measuring range and limitations of the device [39–41].

Zhang describes the potential application of nanosensors in dissolved gases for the detection in oil-insulated transformers in this contribution. Here, it is approached on the adsorption processes between modified CNTs (CNTs-OH, Ni-CNTs) and dissolved gases in transformers oil including C_2H_2, C_2H_4, C_2H_6, CH_4, CO, and H_2 which have been simulated based on the first principle theory. Additionally, the density of states, adsorption energy, charge transfer amount, and adsorption distance of adsorption process between CNTs and dissolved gas were also calculated in his chapter. Two kinds of sensors, mixed acid-modified CNTs and $NiCl_{2}$-modified CNTs, were prepared to conduct the dissolved gases response experiment. Afterward, the gas response mechanisms were investigated. Finally, the results between response experiment and theoretical calculation were compared, reflecting a good coherence with each other. The carbon nanotube (CNT) based gas sensors possess a relatively high sensitivity and fine linearity and could be employed in dissolved gas analysis equipment in the transformer [42–47].

Finally, this book generally reviews the recent and advanced methods and substantial applications of biosensors, gas sensor and chemical sensors. Contributed chapters are scratched by expert scientists and professors in the electrochemical sensor field. This book aims to make a connection between undergraduates, post-graduates, graduates, and scientists on their researches in sensor development based on enzyme-based sensors, graphene-based sensors, NOx sensors, gas sensors, hazardous and toxic gas sensors, and nano-sensors in environmental and biomedical sciences in order to initiate researchers into various sensors study in as straightforward a way as possible and as well as present the scientist the opportunities offered by the health care science and ecological fields. However, each chapter delivers methodological details beyond the level originally in representative journal articles and explores the potential applications of biological and chemical sensors to a substantial level in health care, real clinical, food, industrial, cancer diagnostics, biomedical, environmental science and detection of infectious organisms, also providing a brochure for the future as well as in the safety and security arena. The primary target audience for this book "**Electrochemical Sensors Technology**" includes students, researchers, technologists, physicists, chemists, biologists, engineers, and professionals who are interested in bio, chemi, and gas sensors and associated topics.

Author details

Mohammed Muzibur Rahman* and Abdullah Mohamed Asiri

*Address all correspondence to: mmrahmanh@gmail.com

Center of Excellence for Advanced Materials Research (CEAMR) & Chemistry Department, King Abdulaziz University, Jeddah, Saudi Arabia

References

[1] Alam MK, Rahman MM, Abbas M, Torati SR, Asiri AM, Kim D, Kim CG. Ultra-sensitive 2-nitrophenol detection based on reduced graphene oxide/ZnO nanocomposites. Journal of Electroanalytical Chemistry. 2017;**788**:66-73

[2] Hussain MM, Rahman MM, Arshad MN, Asiri AM. Hg^{2+} Sensor Development Based on (*E*)-N′-Nitrobenzylidene-Benzenesulfonohydrazide (NBBSH) Derivatives Fabricated on a Glassy Carbon Electrode with a Nafion Matrix. ACS Omega. 2017;**2**:420-431

[3] Rahman MM, Jamal A, Khan SB, Faisal M. Cu-doped ZnO based nanostructured materials for sensitive chemical sensor applications. ACS Applied Material and Interfaces. 2011;**3**:1346-1351

[4] Rahman MM, Balkhoyor HB, Asiri AM. Phenolic sensor development based on chromium oxide-decorated carbon nanotubes for environmental safety. Journal of Environmental Management. 2017;**188**:228-237

[5] Rahman, A Jamal, SB Khan, M Faisal. Fabrication of highly sensitive ethanol chemical sensor based on Sm-Doped Co_3O_4 nano-kernel by solution method. Journal of Physical Chemistry. 2011;**C 115**:9503-9510

[6] Rahman MM, A Jamal, SB Khan, M Faisal. Highly sensitive ethanol chemical sensor based on Ni-doped SnO_2 nanostructure materials. Biosensors and Bioelectronics. 2011;**28**: 127-134

[7] Umar A, Rahman MM, Kim SH, Hahn YB. Zinc oxide nanonail based chemical sensor for hydrazine detection. Chemical Communication. 2008:166-169. DOI:10.1039/B711215G

[8] Rahman MM, Hussain MM, Asiri AM. A novel approach towards the hydrazine sensor development by SrO.CNT nanocomposites. RSC Advances.2016;**6**:65338-65348

[9] Rahman MM, Abu-Zied BM, Hasan MM, Asiri AM, Hasnat MA. Fabrication of selective 4-aminophenol sensor based on H-ZSM-5 zeolites deposited silver electrodes. RSC Advances. 2016;**6**:48435-48444

[10] Black DW, Andreasen NC. Introductory Textbook of Psychiatry. 6th ed. Arlington: American Psychiatric Publishing; 2014

[11] Ronkainen NJ, Okon SL. Nanomaterial-based electrochemical immunosensors for clinically significant biomarkers. Materials. 2014;**7**:4669-4709

[12] Hussain MM, Rahman MM, Asiri AM. Sensitive L-Leucine sensor based on a glassy carbon electrode modified with SrO nanorods. Microchimica Acta. 2016;**183**:3265-3273

[13] Rahman MM. Fabrication of mediator-free glutamate sensors based on glutamate oxidase using smart micro-devices. Journal of Biomedical Nanotechnology. 2011;**7**:351-357

[14] Rahman MM, Asiri AM. Development of Penicillin G biosensor based on Penicillinase enzymes immobilized biochips. Biomedical Microdevices. 2015;**17**:9

[15] Rahman MM, Asiri AM. One-step electrochemical detection of cholesterol in presence of suitable $K_3Fe(CN)_6$/phosphate buffer mediator by an electrochemical approach. Talanta. 2015;**140**:96-101

[16] Rahman MM, Asiri AM. Selective choline biosensors based on choline oxidase co-immobilized into self-assembled monolayers on micro-chips at low potential. Analytical Methods. 2015;**7**:9426-9434

[17] Hussain MM, Rahman MM, Asiri AM, Awual MR. Non-enzymatic simultaneous detection of L-glutamic acid and uric acid using mesoporous Co_3O_4 nanosheets. RSC Advances. 2016;**6**:80511-80521

[18] Rahman MM, Hussain MM, Asiri AM. A glutathione biosensor based on a glassy carbon electrode modified with CdO nanoparticles-decorated carbon nanotube in a nafion matrix. Microchimica Acta. 2016;**183**:3255-3263

[19] Field JR, Walker AG, Conn PJ. Targeting glutamate synapses in schizophrenia). Trends in Molecular Medicines. 2011;**17**:689-698

[20] Rahman MM, Ahmed J, Asiri AM. A glassy carbon electrode modified with γ-Ce2S3-decorated CNT nanocomposites for uric acid sensor development: A real sample analysis. RSC Advances. 2017;**7**:14649-14659

[21] Ronkainen NJ, Halsall HB, Heineman WR. Electrochemical biosensors. Chemical Society Reviews. 2010;**39**:1747-1763

[22] Wang J, Musameh M. Carbon nanotube/Teflon composite electrochemical sensors and biosensors. Analytical Chemistry. 2003;**75**:2075-2079

[23] Halder A, Zhang M, Chi Q. Electroactive and biocompatible functionalization of graphene for the development of biosensing platforms. Biosensors And Bioelectronics. 2017;**87**:764-771

[24] Rahman MM, Ahmed J, Asiri AM. Development of creatine sensor based on antimony-doped Tin oxide (ATO) nanoparticles. Sensors and Actuators B: Chemical. 2017;**242**:167-175

[25] Zhu N, Han S, Gan S, Ulstrup J, Chi Q. Graphene paper doped with chemically compatible Prussian Blue nanoparticles as nanohybrid electrocatalyst. Advanced Functional Materials. 2013;**23**:5297-5306

[26] Zhang M, Hou C, Halder A, Ulstrup J, Chi Q. Interlocked graphene Prussian blue hybrid composites enable multifunctional electrochemical applications. Biosensors And Bioelectronics. 2017;**89**:570-577

[27] Lee SR,Rahman MM, Ishida M, Sawada K. Fabrication of a highly sensitive penicillin sensor based on charge transfer techniques. Biosensensors and Bioelectronics. 2009;**24**:1877-1882

[28] Zhang M, Hou C, Halder A, Chi Q. Ultralight, flexible and semi-transparent metal oxide papers for photoelectrochemical water splitting. ACS Applied Materials And Interfaces. 2017;**9**:3922-3930

[29] Zhang M, Halder A, Hou C, Ulstrup J, Chi Q. Free-standing and flexible graphene papers as disposable non-enzymatic electrochemical sensors. Bioelectrochemistry. 2016;**109**:87-94

[30] Lee SR, Rahman M, Ishida M, Sawada K. Development of highly sensitive acetylcholine sensor based on acetylcholine by charge transfer techniques esterase using smart biochips. Trends in Analytical Chemistry. 2009;**28**:196-203

[31] Zhang M, Hou C, Halder A, Wang H, Chi Q. Graphene papers: Smart architecture and specific functionalization for biomimetics, electrocatalytic sensing and energy storage. Materials Chemistry Frontiers. 2017;**1**:37-60

[32] Kharashi K, Murray EP. Effect of Al_2O_3 in porous zirconia electrolytes for NO sensing. Journal of The Electrochemical Society. 2016;**163**:B633-B637

[33] Martin LP, Woo LY, Glass RS. Impedancemetric NO_x sensing using YSZ electrolyte and YSZ/Cr_2O_3 composite electrodes. Journal of The Electrochemical Society. 2007;**154**: J97-J104

[34] Hussain MM, Rahman MM, Asiri AM. Efficient 2-nitrophenol chemical sensor development based on Ce_2O_3 nanoparticles decorated CNT nanocomposites for environmental safety. PLoS ONE. 2016;**11**:e0166265

[35] Woo L, Martin LP, Glass RS, Wensheng W, Sukwon J, Gorte RJ, Murray EP, Novak RF, Visser JH. Effect of electrode composition and microstructure on impedancemetric nitric oxide sensors based on YSZ electrolyte. Journal of the Electrochemical Society. 2008;**155**:J32-J40

[36] Arshak K, Moore E, Lyons GM, Harris J, Clifford S. A review of gas sensors employed in electronic nose applications. Sensor Review. 2004;**24**:181-198

[37] Rahman MM, Balkhoyor HB, Asiri AM. Ultrasensitive and selective hydrazine sensor development based on Sn/ZnO nanoparticles. RSC Advances. 2016;**6**:29342-29352

[38] Zhuiykov S, Miura N. Development of zirconia-based potentiometric NO*x* sensors for automotive and energy industries in the early 21st century: What are the prospects for sensors?Sensors and Actuators B. 2007;**212**:639-651

[39] Noordally E, Richmond JR, Tahir SF. Destruction of volatile organic compounds by catalytic oxidation. Catalysis Today. 1993;**17**:359-366

[40] Rahman MM, Ahmed J, Asiri AM, Siddiquey IA, Hasnat MA. Development of ultrasensitive hydrazine sensor based on facile CoS_2-CNT nanocomposites. RSC Advances. 2016;**6**:90470-90479

[41] Hodgson AT, Faulkner D, Sullivan DP, DiBartolomeo DL, Russell ML, Fisk WJ. Effect of outside air ventilation rate on volatile organic compound concentrations in a call center. Atmospheric Environment. 2003;**37**:5517-5527

[42] Zhang X, Gui Y, Dai Z. A simulation of Pd-doped SWCNTs used to detect SF_6 decomposition components under partial discharge. Applied Surface Science. 2014;**315**:196-202

[43] Zhang X, Chen Q, Tang J, Hu W, Zhang J. Adsorption of SF_6 decomposed gas on anatase (101) and (001) surfaces with oxygen defect: A density functional theory study. Scientific Reports. 2014;**4**:4762

[44] Rahman MM, Jamal A, Khan SB, Faisal M, Asiri AM. Fabrication of highly sensitive acetone sensor based on sonochemically prepared as-grown Ag_2O nanostructures. Chemical Engineering Journal. 2012;**192**:122-128

[45] Zhang X, Tie J, Zhang J. A Pt-doped TiO_2 nanotube arrays sensor for detecting SF_6 decomposition products. Sensors. 2013;**13**:14764

[46] Ebbesen TW, Ajayan PM. Large-scale synthesis of carbon nanotubes. Nature. 1990;**358**: 220-222

[47] Zhang X, Gui Y, Dong X. Preparation and application of TiO_2 nanotube array gas sensor for SF_6-insulated equipment detection: A review. Nanoscale Research Letters. 2016;**11**: 1-13