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"Nanotechnology and Biosensors"

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Introduction

"Nanotechnology and Biosensors" is published by Elsevier, The Netherlands, under the Micro and Nano Technologies series of the Materials Science subject area. The text is a collection of fourteen collaboratively authored chapters which have been edited by father and daughter, Dimitrios P. Nikolelis and Georgia-Paraskevi Nikoleli, affiliated with the University of Athens, Greece.

This text discusses progress made in the fields of nanotechnology and chemical sensing to give a concise picture of the combined application of nanobiosensors in health screening, food safety and environmental analysis over the past 20 years. It highlights the unique properties of nanomaterials, which impart enhanced biosensing performance such as very low limits of detection and potential for small, portable and cost-effective point-of-care devices with rapid results. Within the fourteen chapters, the reader finds information relating to chemical receptors and signal output transducers including: materials preparation, device design, sample preparation, detection mechanisms, signal processing and output. Each chapter discusses a nanomaterial, a transducing technology or sensing application and can therefore be read individually, although those looking for a general overview of nanomaterials and biosensors will need to read the entire text to fully appreciate the scope of the application of nanotechnology in the field of biosensors. The contents of each chapter are summarised in the preface which is available online (1).

Nanomaterials

Nanotechnology encompasses synthesis, analysis and manipulation of materials which have a dimension in the range of 1–100 nm. There is great interest in nanomaterials because the physicochemical properties differ greatly from those of the bulk materials. This text discusses how the unusual properties of these materials can be exploited to develop small, portable, highly sensitive (down to atto- or zepto-molar), rapid and inexpensive biosensors that can be used by the untrained person.

Nanomaterials discussed in the text include metals (silver, gold and platinum) and metal oxides (iron(II,III) oxide, zinc oxide, nickel(II) oxide and titanium dioxide) but carbon features most prominently. Carbon occurs in many forms and feedstocks are abundant and inexpensive. Carbon nanomaterials discussed include: graphene, graphite, carbon nanotubes, diamond and boron doped diamond, dendrimers, polymers and conducting polymers. Chapters 3, 4, 9 and 10 introduce the many forms of carbons as well as how they are made, processed and functionalised with sensing moieties. Surface structure, size, defect and doping of carbon nanotubes and graphene have been shown to impart crucial properties such as kinetics of charge transfer or efficacy of functionalisation which in turn influence the performance of the biosensor as discussed in Chapters 3 and 4. In Chapter 9, the authors highlight the ease of functionalisation and discuss how the increased surface area of carbon nanomaterials is key to enhanced biosensing performance while emphasising in their conclusion the lack of breakthrough to commercial scale due to difficulties in fabrication and reproducibility.

Biosensor Form

The output mechanism for most of the biosensor applications discussed in the text are typically electrochemical or optical. The pros and cons of amperometric and impedimetric electrochemical sensors are compared and examples of optical and fluorescent biosensors are provided. Other signal transduction methods discussed include the use of quartz crystal microbalance where the enhanced sensitivity of the vibratory frequency is related to the change in mass of this piezoelectric material utilising nanomaterials. Intracellular biosensors, Chapter 2, are also discussed as a new technology that could bring fundamental changes to measurements and understanding of biological processes in healthcare and treatment of diseases. The benefits and potential applications of nanomaterial functionalised optical fibre biosensors are discussed in the final chapter.

Selectivity in Biosensors

Techniques used to impart specificity of the various types of biosensors are discussed for labelled and label-free biosensors. The methods for functionalisation of the different nanomaterials are discussed for specific receptors or recognition modalities, either synthetic or natural such as enzymes, antibodies or DNA. Different strategies are also discussed in various chapters from covalent bonding to electrostatic interaction. Often, the increased specificity of biosensors based on nanomaterials is attributed to the high surface area available for attachment of the biorecognition moieties. Chapters 11 and 12 describe very well the methods used for DNA functionalisation of gold and graphene nanomaterials (**Figure 1**).

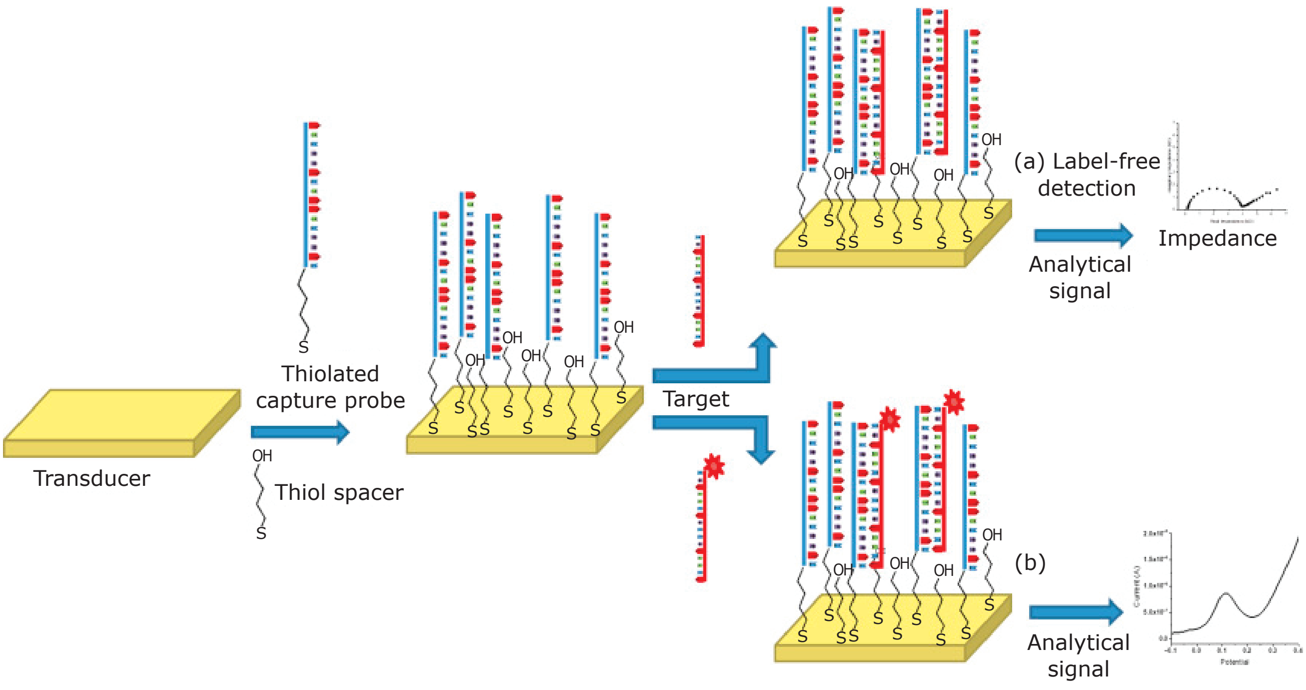

Fig. 1. Functionalisation of an electrochemical biosensor electrode for: (a) direct electrochemical gene detection; (b) labelled electrochemical gene detection. Reproduced with permission from Elsevier, copyright (2018) Elsevier

Microfluidics

The penultimate chapter in the book discusses the integration of microfluidics into biosensors not only for sample preparation but also in the context of lab-on-a-chip biosensors where a range of complex processes can be carried out on a very small sample size to give qualitative and quantitative results in the field.

Applications

The text relates the advances made in nanomaterials and biosensing to real-world applications including environmental and food toxicant detection as well as healthcare. It is perceived that the scope for application of nanobiosensors in healthcare is enormous, simply because of the breadth of this subject and setting. For example, nanobiosensors could be used to detect and monitor medical conditions in many environments including: domestic, GP surgery, emergency care, hospital wards and nursing homes. Chapter 1 presents a broad overview of nanomaterials and their incorporation in the design of devices for chemical or microbiological sensing of food and environmental toxicants and some examples in healthcare applications. It is concluded that although nanotechnology shows promise for rapid detection in real-time applications, some technical challenges remain before its potential is fully realised. Many chapters discuss the application of nanomaterials to healthcare ranging from glucose sensing in Chapter 2 to cardiac and cancer biomarker detection in Chapter 9.

Therapeutic Nanomaterials

Chapters 5 and 6 are slightly differentiated from the other chapters in that they discuss the application of nanomaterials in so-called theranostics where nanoparticles can be used as a sensor to locate a specific target or be navigated to a target whilst simultaneously delivering a therapy. Chapter 5 discusses how the plasmonic resonance of gold nanomaterials can be tuned as a function of size and shape and this can be exploited in photothermal and photodynamic therapy where the particles accumulate in cancerous tissue and the specific plasmon resonance frequency can be controllably excited to impart thermal energy which is then transferred to the accumulative tissue, destroying it. The tracking and manipulation of magnetic nanomaterials to encapsulate and deliver pharmaceuticals to target areas within the body is discussed in Chapter 6.

Fibre Optic Sensors

Chapter 14 discusses how the functionalisation of optical fibres with nanomaterials can lead to development of optoelectronic biosensors which are sufficiently more sensitive than existing spectroscopic imaging and sensing optical fibre technologies such that they can be smaller and more portable for application outside of the specialist environment. A particular benefit of optoelectronic sensors over electrochemical biosensors is the ability to detect and characterise species directly in biological samples or even non-invasively without the need for sample preparation, such as in transdermal blood glucose monitoring.

Conclusion

This text covers a lot of ground and will be of interest to those wishing for a general overview of the range of nanomaterials used for biosensing in environmental, food and medical sensing applications. There is some repetition of introduction and technical detail between the chapters which allows them to be read in isolation and all are well referenced for those looking for more detail in a particular application.

References

1. 'Preface', in "Nanotechnology and Biosensors", 1st Edn., eds. D. Nikolelis and G. P. Nikoleli, Micro and Nano Technologies Series, Elsevier, Amsterdam, The Netherlands, 2018, pp xix–xxvi

The Reviewers

Bénédicte Thiébaut received her PhD from Heriot-Watt University, UK, in the field of coordination chemistry. Since joining Johnson Matthey, UK, she has gained expertise in nanomaterials syntheses and their applications in catalysis, pigmentation and sensing with a focus on biosensing. Currently, she is the Technology Director for the Medical Device Components business, leading research into technologies in the manufacture of platinum group metal and Nitinol components for implantable devices which find application in vascular, cardiac rhythm management and neurostimulation markets.

Ross Gordon received his PhD from the University of Edinburgh, UK, in the field of coordination chemistry and ligand design for metal recovery. Since joining Johnson Matthey, UK, in 2009 he has worked in the fields of printed electronics and precious metal recycling. He is currently Principal Scientist in the Catalyst & Materials Group at Johnson Matthey, Sonning Common, UK, working with the Medical Device Components business.

