Analytica Chimica Acta 959 (2017) 15–42

Contents lists available at ScienceDirect

Analytica Chimica Acta

journal homepage: www.elsevier.com/locate/aca

Review

How cutting-edge technologies impact the design of electrochemical (bio)sensors for environmental analysis. A review

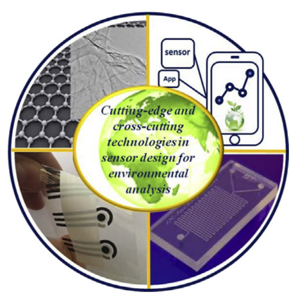
Fabiana Arduini [a, b, *], Stefano Cinti [a], Viviana Scognamiglio [c], Danila Moscone [a, b], Giuseppe Palleschi [a, b]

[a] Department of Chemical Science and Technologies, University of Rome "Tor Vergata", Via della Ricerca Scientifica, 00133 Rome, Italy
[b] National Institute of Biostructures and Biosystems "INBB", Viale Medaglie d'Oro, 305, Rome, Italy
[c] Institute of Crystallography (IC-CNR), Via Salaria Km 29.300, 00015, Monterotondo, Rome, Italy

HIGHLIGHTS

- Cutting-edge technologies in biosensor fabrication for the detection of pollutants.
- Printed sensors, nanomaterials, nanomotors, biomimetic design, lab on a chip are described.
- Futuristic cross-cutting technologies for innovative aspects of (bio)sensors are reported.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 May 2016
Received in revised form
19 December 2016
Accepted 22 December 2016
Available online 2 January 2017

Keywords:
Pollutants
Printed (bio)sensors
Nanomaterials
Artificial bioreceptors
Lab-on-a-chip

ABSTRACT

Through the years, scientists have developed cutting-edge technologies to make (bio)sensors more convenient for environmental analytical purposes. Technological advancements in the fields of material science, rational design, microfluidics, and sensor printing, have radically shaped biosensor technology, which is even more evident in the continuous development of sensing systems for the monitoring of hazardous chemicals. These efforts will be crucial in solving some of the problems constraining biosensors to reach real environmental applications, such as continuous analyses in field by means of multi-analyte portable devices. This review (with 203 refs.) covers the progress between 2010 and 2015 in the field of technologies enabling biosensor applications in environmental analysis, including i) printing technology, ii) nanomaterial technology, iii) nanomotors, iv) biomimetic design, and (v) microfluidics. Next section describes futuristic cutting-edge technologies that are gaining momentum in recent years, which furnish highly innovative aspects to biosensing devices.

Contents

* Corresponding author. Department of Chemical Science and Technologies, University of Rome "Tor Vergata", Via della Ricerca Scientifica, 00133, Rome, Italy.
E-mail address: fabiana.arduini@uniroma2.it (F. Arduini).

http://dx.doi.org/10.1016/j.aca.2016.12.035
0003-2670/

1. Introduction

In the last decades, due the industrial globalization and the rise in population, the increasing amount of hazardous compounds that have high impact on human wellbeing and environmental health have been of increasing concern. These chemicals include heavy metal ions, pesticides, phenolic compounds, xenobiotics, and hydrocarbons to name a few. Over the past century, they have been widely disseminated into the environment and some of them have never undergone safety testing, and a minimal assessment has been provided on their potential toxicity or the possible synergistic effects of simultaneous exposures to multiple chemicals [1,2].

Among these chemicals, emerging substances have received a huge attention because of their increasing presence in the environment, their potential threats to environmental ecosystems, and the absence of routine monitoring programmes at the European level. Due to their high relevance, these substances have been identified by the NORMAN Group (Network of reference laboratories, research centres and related organizations for monitoring emerging environmental substances) and enclosed in a list of priority substances, whose latest update was provided on February 2016 [3]. Emerging substances encompass a miscellaneous group of compounds, including pharmaceuticals and personal-care products, drugs of abuse and their metabolites, steroids and hormones, endocrine-disrupting compounds, surfactants, perfluorinated compounds, phosphate ester flame retardants, industrial additives and agents (e.g. benzotriazoles and benzothiazoles), siloxanes, artificial sweeteners, biocides, polar pesticides and their degradation products, and gasoline additives [4].

For these reasons, important pollution issues persist for several countries considering that the hazardous compounds represent an important risk for environmental and human health, food security, and ecosystem resilience. For example, the veterinary use of diclofenac, a human pharmaceutical used for anti-inflammatory treatment, has been found to be responsible for the massive decline in populations of vulture species in certain areas of Asia; ethinyl estradiol, an active ingredient of contraceptive pills, has been associated with endocrine disruption in fish; lastly, the long-term exposure to antibiotics, used in human and veterinary medicine, may contribute to the selection of resistant bacteria in the environment which may have significant implications for human health [5].

Moreover, environmental pollution is nowadays recognized as a major cause of illness and mortality in both developed and developing countries, being responsible for 8.9 million deaths around the world each year according to the World Health Organization [6], and having great economic costs which burden on the national health care systems of countries around the world [7].

Therefore, there is an increasing demand to develop joint technological solutions for pollution monitoring and management. Undeniably, a holistic approach combining cutting-edge technologies in sensor development can envisage the construction and assembling of smart analytical tools able to characterise the extent of contamination at relevant spatial scales and in terms of its eco-effects, and to provide an inclusive and representative picture of the quality of the environment [8]. Indeed, while the presence and the effects of metals, bacteria, hydrocarbons, nitrates and ammonia in water have been described for several decades, the occurrence of phthalates, pharmaceuticals compounds, PAHs, PCBs, and Bisphenol A is often not available.

As extensively reviewed by Geissen and coworkers [9], there are several challenges regarding the detection of hazardous chemicals. Among them, spatial and temporal distribution is also important, since intra-day and inter-day variations, seasonality and occasional events can influence the attainment of a harmonised screening. In this context, the exploitation of conventional analytical techniques to monitor hazardous chemicals requires the collection of repeated spot sampling (time and cost consuming), their analyses done by laboratory set-up instruments, with the evaluation of the risks/effects, providing only snapshot data of contaminated areas without realistic information on spatio-temporal variations in the composition of real samples and their relative effects. Among standard techniques, chromatographic methods have provided reliable identification and quantification of compounds at ultratrace level, but their high cost and lack of portability for in field analysis are the major drawbacks. Moreover, obstacles related to classical technologies (i.e. time and cost consuming repeated spot sampling, sample collection and transport, employment of skilled personnel, failing in providing data on global toxicity) could have detrimental implications in terms of regulatory analyses and accurate monitoring of environmental quality.

In this context, (bio)sensor technology allows to design ad hoc analytical systems which include a combination of advantages, in terms of reduced time-to-result; automation and miniaturisation,