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Review

Graphene-based materials for the electrochemical determination of hazardous ions

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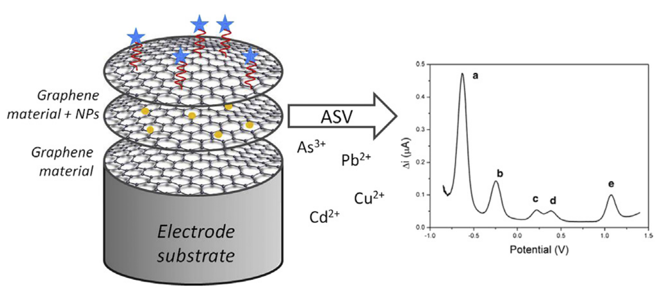
HIGHLIGHTS

- This paper reviews the use of graphene for the electroanalysis of hazardous ions.
- The use of graphene for As(III), Cd^{2+}, Pb^{2+}, Hg^{2+}, Cr(VI), etc. analysis is reported.
- Graphene is interesting for sensors due to: their conductivity and high surface area.
- Graphene can be easily functionalized with nanoparticles or other chemicals.
- Selectivity of the electrodes can be improved with the use of organic materials.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of graphene in the field of electrochemical sensors is increasing due to two main properties that make graphene and derivatives appealing for this purpose: their conductivity and high surface area. In addition, graphene materials can be easily functionalized with nanoparticles (Au, Pt, etc.) or organic molecules (DNA, polymers, etc.) producing synergies that allow higher sensitivity, lower limit of detection as well as increased selectivity. The present review focuses on the most important works published related to graphene-based electrochemical sensors for the determination of hazardous ions (such as As(III), Cd^{2+}, Pb^{2+}, Hg^{2+}, Cr(VI), Cu^{2+}, Ag^{+}, etc.). The review presents examples of the use of graphene-based electrodes for this purpose as well as important parameters of the sensors such as: limit of detection, linear range, sensitivity, main interferences, stability, and reproducibility. The application of these graphene-based electrodes in real samples (water or food matrices) is indicated, as well. There is room for improvement of these type of sensors and more effort should be devoted to the use of doped graphene (doped for instance with N, B, S, Se, etc.) since electrochemically active sites originated by doping facilitate charge transfer, adsorption and activation of analytes, and fixation of functional moieties/molecules. This will allow the sensitivity and the selectivity of the electrodes to be increased when combined with other materials (nanoparticles/organic molecules).

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Abbreviations

ABS	Acetate buffer solution
AdDPCSV	Adsorptive differential pulse cathodic stripping voltammetry
ARGO	Activated reduced graphene oxide
ASLSV	Anodic stripping linear sweep voltammetry
ASV	Anodic stripping voltammetry
BF	bismuth film
BFE	Bismuth film electrode
C	Concentration
CC	Chronocoulometry
CPE	Carbon paste electrode
CTAB	Cetyltrimethylammonium bromide
CV	Cyclic voltammetry
CVD	Chemical vapor deposition
DNA	Deoxyribonucleic acid
DPASV	Differential pulse anodic stripping voltammetry
DPV	Differential pulse voltammetry
DTT	Diaminoterthiophene
EDTA	ethylenediaminetetraacetate
EIS	Electrochemical impedance spectroscopy
ERGO	Electrochemically reduced graphene oxide
G	Graphene
GCE	Glassy carbon electrode
GNS	Graphene nanosheets
GO	Graphene oxide
GQD	Graphene quantum dot
GRC	Graphite reinforced carbon
GS	Graphene sheet
HER	Hydrogen evolution reaction
IL	Ionic liquid
ITO	Indium tin oxide
LSV	Linear sweep voltammetry
MFE	Mercury film electrode
MTU	5-methyl-2-thiouracil
MWCNTs	Multiwalled carbon nanotubes
nanoG	Nanographene
NP	Nanoparticle
NPC	Nanoporous carbon
ocp	Open circuit potential
OSWV	Osteryoung square wave voltammetry
PAH	polyallylamine hydrochloride
Pani	Polyaniline
PBS	Phosphate buffer solution
PEDOT	Poly(3,4-ethylenedioxythiophene)
PEI	Polyethyleneimine
PGE	Pencil graphite electrode
poly-p-ABSA	poly(p-aminobenzene sulfonic acid)
po-G	Partially oxidized graphene
PPAA	Plasma polymerized allylamine
PPy	Polypyrrole
PS	Polystyrene
PSA	Potentiometric stripping analysis
PSS	poly(styrenesulfonate)
PVDF	polyvinylidene difluoride
PVP	polyvinylpyrrolidone
QCM	Quartz crystal microbalance
QD	Quantum dot
RGO	Reduced graphene oxide
RSD	Relative standard deviation
SA	Sodium alginate
SDS	Sodium dodecyl sulfate
ssDNA	Single stranded DNA
SPCE	Screen printed carbon electrode
SPE	Screen printed electrode
STP	Sulfonate-terminated polymer
SWASV	Square-wave anodic stripping voltammetry
SWV	Square wave voltammetry
WHO	World Health Organization
3DAGNs	Three-dimensional activated graphene networks

Contents

1. Introduction

Graphene, often regarded as the new "miracle material" [1], has emerged as a revolutionary material since its isolation in 2004 by K.S. Novoselov and co-workers [2]. Such consideration arises from properties such as high electron mobility at room temperature