Environmental applications of graphene-based materials

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Nanoparticles and the Environment

- Nature of nanoparticles themselves.
- Characteristics of the products made.
- Manufacturing processes involved.
  - As nano-xyz is manufactured, what materials are used?
- What waste is produced?
- Are toxic substances used in the manufacturing of nano-xyz?
- What happens when nano-xyz gets into the air, soil, water, or biota?

"The emerging fields of nanoscience and nanoengineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical things. This is likely to change the way almost everything - from vaccines to computers to automobile tires to objects not yet imagined - is designed and made."

- Interagency Working Group on Nanoscience, Engineering, and Technology Report (1999)

Nanotechnology -

Possibility for Environmental Benefit

- Improved monitoring & detection capabilities
- **Ultra-Green** manufacturing and chemical processing – eliminate toxic constituents
- Waste-minimization via designed-in pollution prevention at the source - less material to dispose of, atom-by-atom construction
- Reduced energy usage
- Commercially-viable alternative clean energy sources (fuel cells, solar, wind)
- Inexpensive, rapid remediation, treatment and sensing technologies
- Sustainability

Nanotechnology and the Environment

> *"As EPA looks to the future, it will need to employ innovative approaches and sound science to investigate complex, interdisciplinary problems in environmental protection."*
>
> \- EPA FY 2001 Annual Report

Nanotechnology has the potential to substantially benefit environmental quality and sustainability through

- **Pollution prevention**
- **Treatment**
- **Remediation**
- **Information**

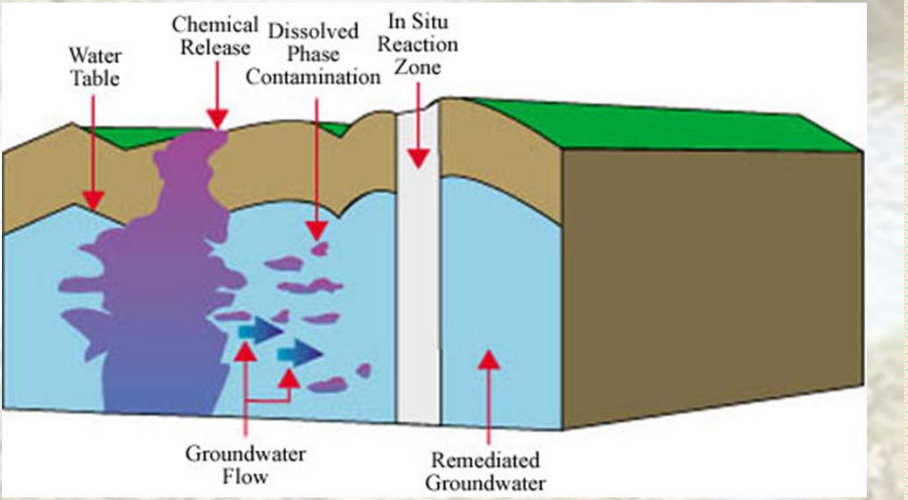
Nanotechnology for pollution prevention

- Synthetic or manufacturing processes which can occur at ambient temperature and pressure.
- Use of non-toxic catalysts with minimal production of resultant pollutants.
- Use of aqueous-based reactions.
- Build molecules as needed --“just in time.”
- Nanoscale information technologies for product identification and tracking to manage recycling, remanufacture, and end of life disposal of solvents.

- Involved in making a manufacturing process environmentally benign.
- An environmentally benign material or manufactured product that replaces toxic substances or minimizes raw materials.

Treatment & Remediation

End-of-pipe management and cleanup of pollution



Applications of graphene-based materials

- Removal of heavy metals such as: Cu(II), Pb(II), Cd(II), CO(II);
- Organic pollutants (benzene containing) with π-π interactions between graphene and the adsorbate;
- Magnetic particles are introduced to form magnetic graphene composites;
- Graphene-based photodegradants for removing organic pollutants;

* Elliot and Zhang *ES&T* **2001**, *35*, 4922-4926

Sensors

Used for

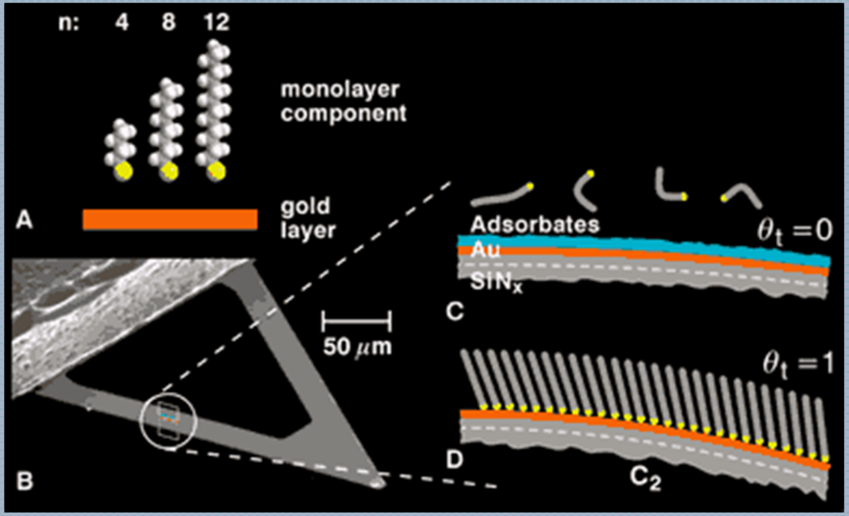
- Process control, compliance and ecosystem monitoring, and data/information interfaces.

Need to be

- Low cost, rapid, precise, and ultra sensitive.
- Operated remotely and continuously, *in situ*, and in real time.

Single Molecule Detection

- Molecules adsorb on surface of micro cantilever, causes a change in surface stress, cantilever bends.
- Used to detect chemicals using either a specific reaction between analyte and sensor layer or chem/physisorption processes.
- Applications to bio-toxins as well.



IBM--Berger et al., Science 1997 June 27; 276: 2021-2024

Nanomaterials in analytical chemistry

- partitioning mechanism of the extraction, which is characterized by significantly higher linearity range when compared to commercial fibre
- enabling highly polar sorbents to be used without the risk of dissolving in polar sample matrix
- povides opportunity of application of quite new kinds of materials, which due to low melting temperatures or solubility in water have not been taken into consideration so far in this kind of applications
- high extraction efficiency of phenols and VOCs obtainable with M-SPME fibres, comparable and better than the extraction efficiency using commercially available fibres

- applicable on the sample preparation step prior to the final quantitative determination of analytes on the ppb level

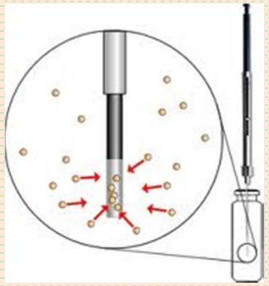
MILESTONES IN ANALYTICAL CHEMISTRY

1974 Development of flow injection analysis - FIA

1974 Development of purge-and-trap technique - PT

1976 Development of **solid phase extraction** - SPE

1978 Development of cloud point extraction - CPE



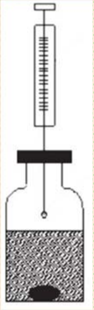
1985 Development of microwave-assisted extraction - MAE
Development of supercritical fluid extraction - SFE

1987 The concept of ecological chemistry (H. Malissa)
The concept of sustainable development

1990 Development of **solid-phase microextraction** - SPME
Development of micro total analysis system - µTAS

1993 Development of molecularly imprinted solid-phase extraction - MIMSPE

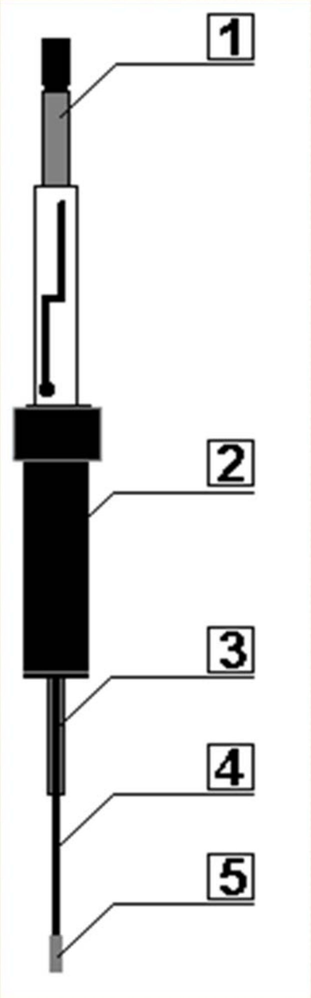
1995 The concept of environmentally friendly analytical chemistry (M. de la Guardia, J. Ruzicka)



1996 Development of presurized solvent extraction - PSE
Development of liquid phase micro extraction - LPME
Development of **single drop microextration** -SDME

1999 The concept of green chemistry (P.T. Anastas)
The concept of clean analytical method (M. de la Guardia)
The concept of green analytical chemistry (J. Namieśnik)
Development of **stir bar sorptive extraction-** SBSE

SOLID PHASE MICROEXTRACTION (SPME)

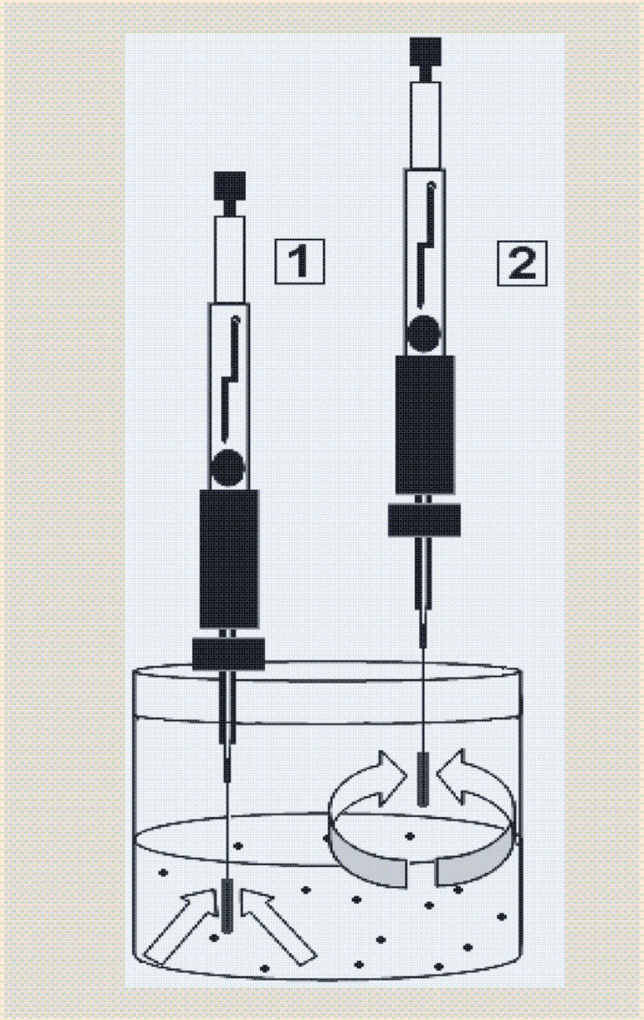


- simplicity of operation
- short extraction and desorption time
- **<u>solvent-free</u>** <u>operation</u>
- small size (convenient for designing portable devices)
- possibility of full automation
- direct linkup with a GC
- possibility to *in-situ* and *in-vivo* sampling

1. Plunger
2. Barrel
3. Injection needle
4. Inner needle
5. Coated fused silica fiber

C. L. Arthur, J. Pawliszyn, *Anal. Chem.*, 62 (1990) 2145

PRINCIPLES OF SPME



1. **direct-immersion SPME**
2. **headspace-SPME**

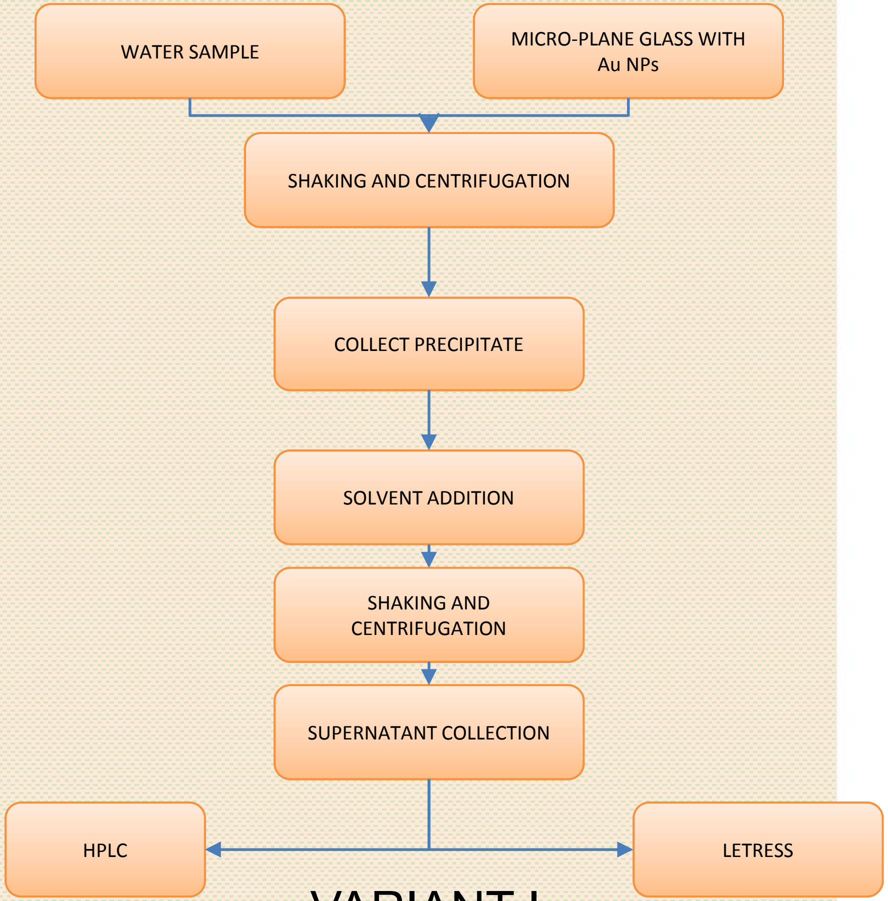
Operation steps:

1. Immersion of the needle in the sample
2. Exposition of the fiber
3. Extraction of an analytes
4. Retraction of the fiber
5. Introduction of the fiber to injection port
6. Desorption of analytes

COMMERCIAL SPME FIBERS

- limited choice
- high cost
- poor selectivity for polar analytes
- some fiber coating have active adsorption centers- possibility of competing of the matrix compounds with the analytes for available adsorbent sites
- need to high temperatures to be used to desorb the less volatile compounds- can lead to degradation of the analytes, adsorbent materials and promote catalytic breakdown of the trapped analytes

APPLICATION OF NANOPARTICLES IN NANOEXTRACTION TECHNIQUES



WATER SAMPLE

MICRO-PLANE GLASS WITH Au NPs

SHAKING AND CENTRIFUGATION

COLLECT PRECIPITATE

SOLVENT ADDITION

SHAKING AND CENTRIFUGATION

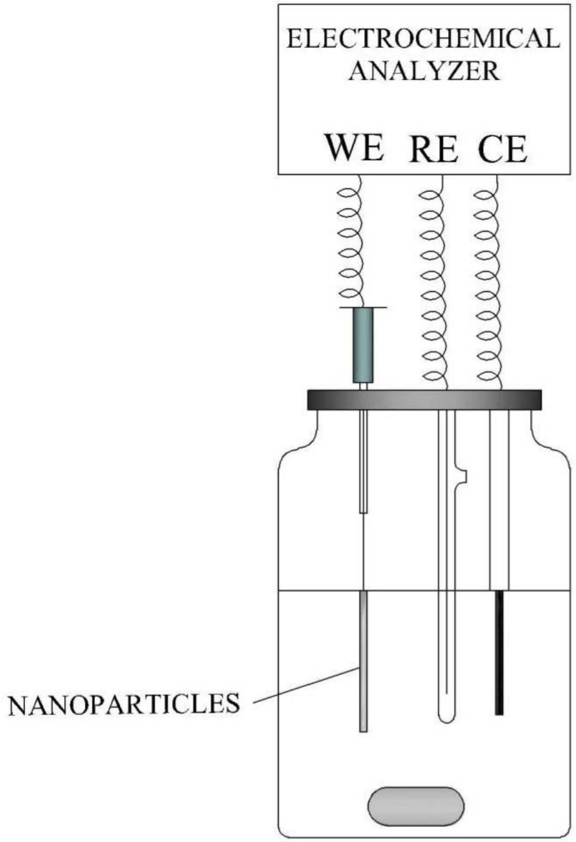
SUPERNATANT COLLECTION

HPLC

LETRESS

VARIANT I

H. Wang, A. D. Campiglia, Anal. Chem., 80 (2008) 8202



VARIANT II

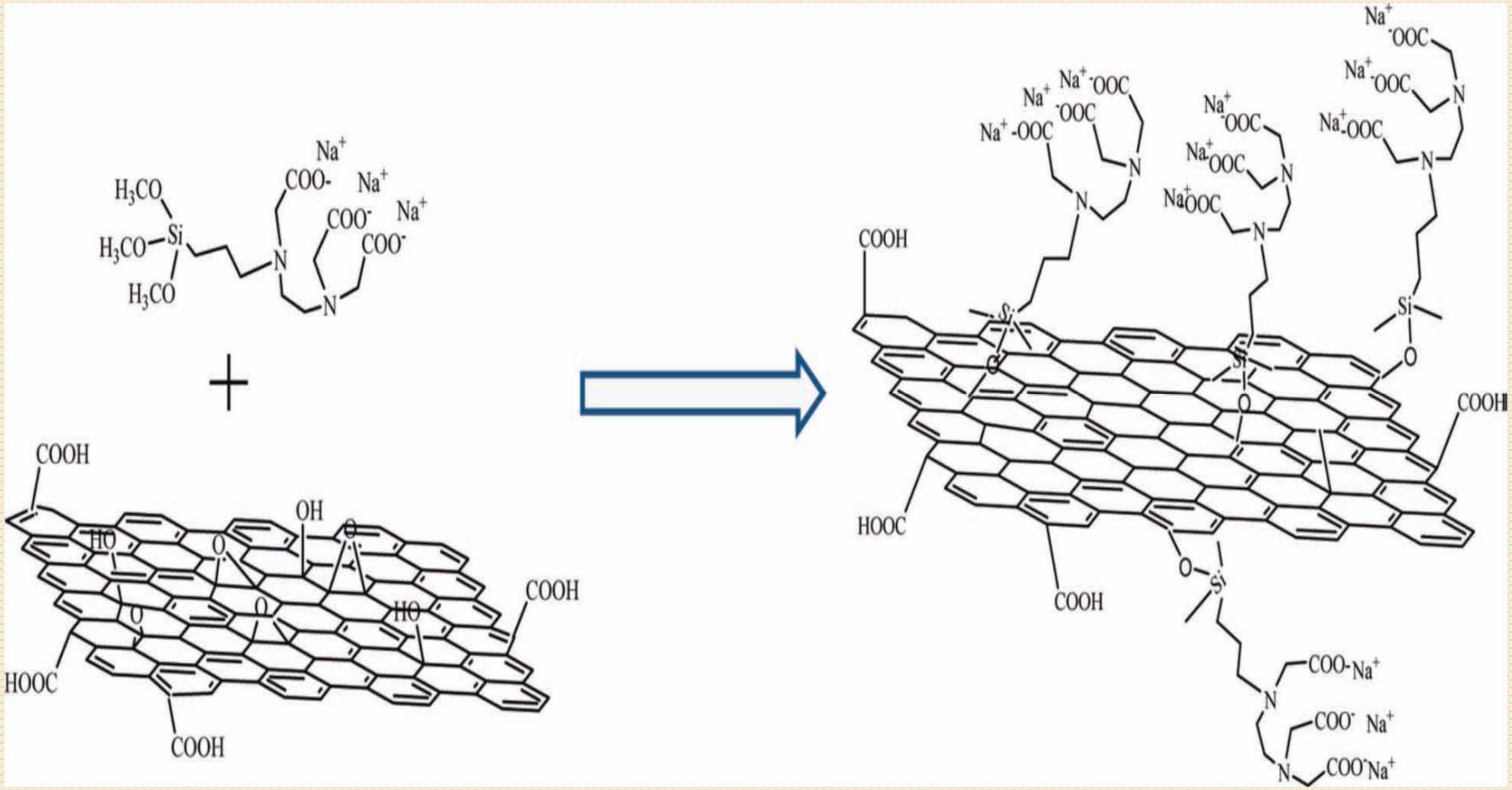
Y. Zhu, S. Zhang, Y. Tang, M. Guo, C. Jin, T. Qi, J Solid State Electrochem, 14 (2010) 1609.

Solid-phase nanoextraction(SPNE)

ADVANCES IN SPME TECHNIQUE

- AUTOMATION
- NEW EXTRACTION PHASE
  - IONIC LIQUIDS
  - CARBON NANOTUBES AND GRAPHEN
  - SILICA MICROSTRUCTURES
- NEW DEVICES AND MODIFICATIONS
  - MEMBRANE-SPME
  - LIQUID-LIQUID-SOLID MICROEXTRACTION
  - ELECTROSORPTION ENHANCED-SPME

Schematic illustration of silanization of graphene



Silanized chemically reduced graphene oxide with improved dispersability

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Representative examples of the use of carbon nanostructures as stationary (GC, LC) and CEC phases

Carbon nanostructure	Separation technique	Column caracteristics	Analytes	Ref
MWCNTs	GC	30 cm lenghtx0.30 cm i.d.Packed glass column	Aromatic hidrocarbons, halogenated hydrocarbons, alcohols, ketones, ester	56
MWCNTs	GC	Stainless steel tub(MWCNTs radically aligned inside)	Alkane and alkene	57
Self assembled SWCNTs	GC	Stainless steel tube	Alkanes and PAHs	58
SWCNTs	Ultrafast GC	100 μm x100 μm square 50 cm long microfabricated channels	Alkanes and functional group mixtures	60
SWCNTs	μ - HPLC	40 cm fused silica capillary monolithic stationary phase	Uracil, phenol,N,N'-diethyl-m-toluamide, toluene	63
Si-SWCNTs and Si-MWCNTs	LC	Narrow-bore stainless steel column	Aromatic compounds	64
SWCNTs-BSA conjugates	Microchip-CE	Protein stationary phase immobilized in a microfluidic chip	Tryptophan enantiomers	65
SWCNTs	CEC	-	Chlorophenols, antiinflammatory drugs and penicillins	66
MWCNTs	CEC	-	Chiral separation of ephedrines	67
β – CD modified MWCNTs	CEC	-	Chiral separation of clenbuterol	68
Fullerene C60	CEC	-	PAHs	69
c- SWCNTs	CEC	-	Caffeine and threobromine	71
SWCNTs	CEZ	-	Purine and pyrimidine bases	72

Determination of phenols using SPME and GC

Compound	Linearity range (µg/L)	R^2	LOD (µg/L)	
			M-SPME	PA
4-Chloro-3-methylphenol	15-1500	0.9953	7	50
2-Chlorophenol	3-300	0.9936	43	530
2,4-Dichlorophenol	3-300	0.9987	15	120
2,4-Dimethylphenol	3-300	0.9921	9	110
2,4-Dinitrophenol	10-1000	0.9963	110	950
2-Methyl-4,6-dinitrophenol	15-1500	0.9898	81	680
2-Nitrophenol	3-300	0.9945	9	60
4-Nitrophenol	15-1500	0.9937	150	1800
Pentachlorophenol	15-1500	0.9914	83	740
2,4,6-Trichlorophenol	10-1000	0.9932	61	440

A. Kloskowski, M. Pilarczyk, J. Namieśnik, Anal. Chem., 81 (2009) 7363

Adsorption of Organic Contaminants from Solution to xGNPs

Batch Adsorption/Desorption Study:

xGNPs large aggregates

xGNPs small aggregates

xGNPs colloidal particles

Adsorption of naphthalene onto carbonaceous nanomaterials graphite nanoplatelets in aqueous solutions

In this paper, we report the adsorption of naphthalene on exfoliated graphite nanoplatelets (xGnP) in aqueous systems, in the presence of small concentrations of NOM. The effect of the process variables: contact time and initial concentration of the adsorbate over the naphthalene adsorption is reported

All adsorption isotherms were fitted well by Freundlich model and using the Freundlich isotherm, the adsorption capacity of naphthalene on xGnP was calculated to be 1.1652.

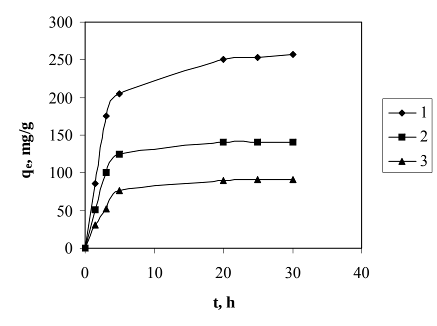


Fig. 3. The effect of the initial naphthalene concentration on the equilibration time. The concentration of naphthalene: (1) 10-4 M; (2) 5x10-4 M; (3) 3x10-4 M.

ISOTHERM PARAMETERS OBTAINED BY USING LINEAR METHOD

Isotherm type	Parameter	Value
Freundlich	K_F, $(mg/g)(L/g)^{nF}$ 1/n, R^2	1.1652 0.316 0.9895
Langmuir	$q_{m,}$ mg g^{-1} K_a R^2	0.00162 18.43 0.8683

FREUNDLICH ISOTHERM PARAMETERS FOR OTHER CARBON MATERIALS USED AS SORBENTS FOR NAPHTALENE, AS REPORTED BY OTHER INVESTIGATORS, LISTED TOGETHER WITH THE xGnP RESULTS FROM THIS STUDY

Sorbent	K_F, $(mg/g)(L/mg)^{nF}$	n	Reference
Activated carbon	200.2	0.35	This work
xGnP as received	1.1652	0.56	This work
Nano-C60	50	0.1	[28]
Charcoal	1.7	0.32	[18]

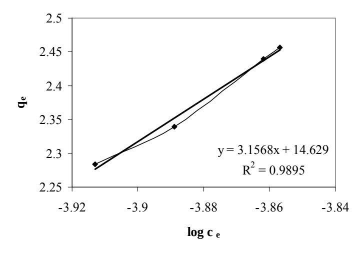


Fig. 5. Freundlich isotherm for the adsorption of naphthalene on xGnP.

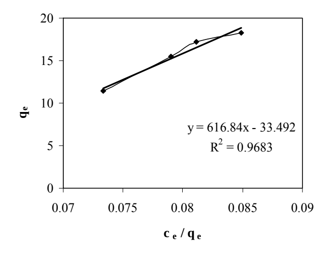
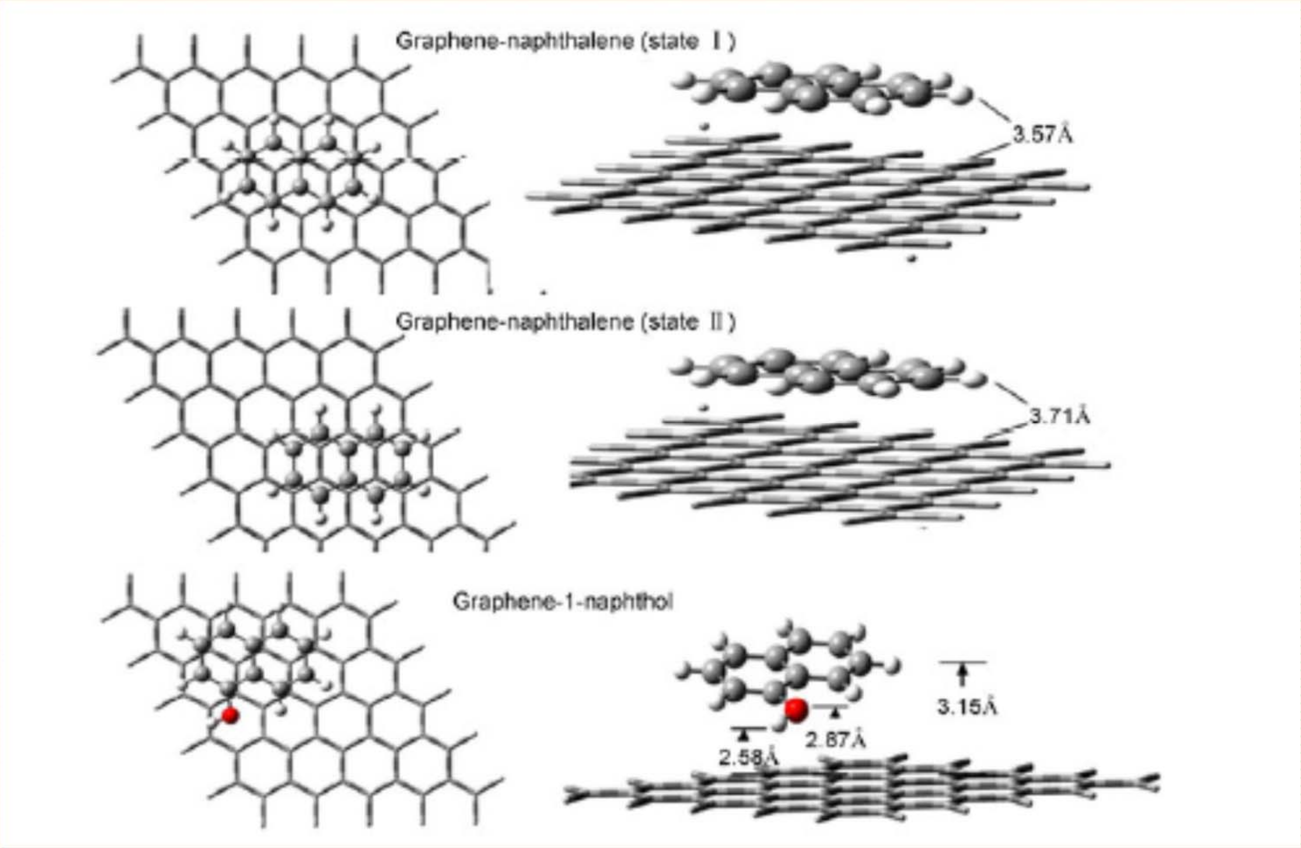


Fig. 6 Langmuir isotherm for the adsorption of naphthalene on xGnP.

A.C. Ion, A. Alpatova, I. Ion, research report 2010

Top view and side view of naphthalene and 1-naphthol on the hexagonal carbon network



Naphtalene molecules adsorbed parallel to the sulfonated graphene surface in two orientations and 1-naphtol in one orientation

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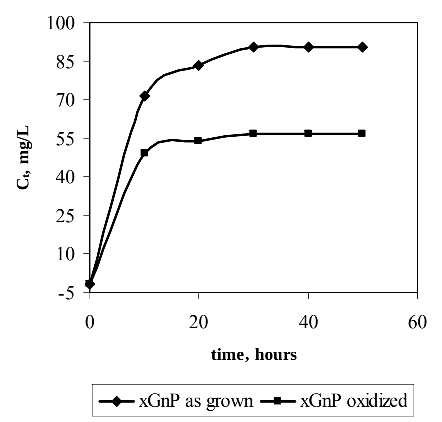
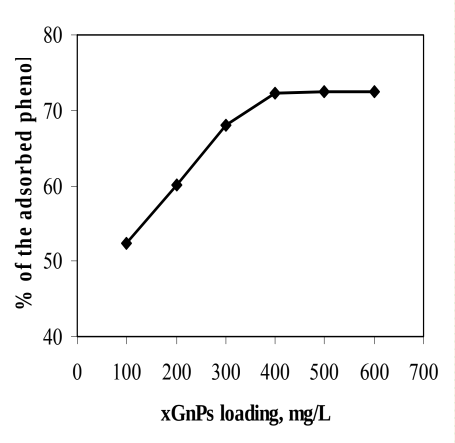
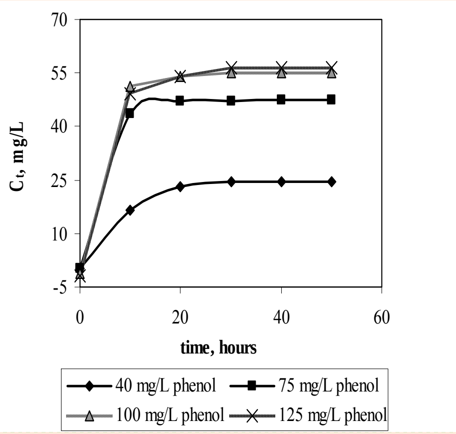
Study on phenol adsorption from aqueous solutions on exfoliated graphitic nanoplatelets



Effect of contact time on phenol adsorption to 400 mg/L xGnPs at 125 mg/L initial phenol concentration for as-grown and oxidized xGnP



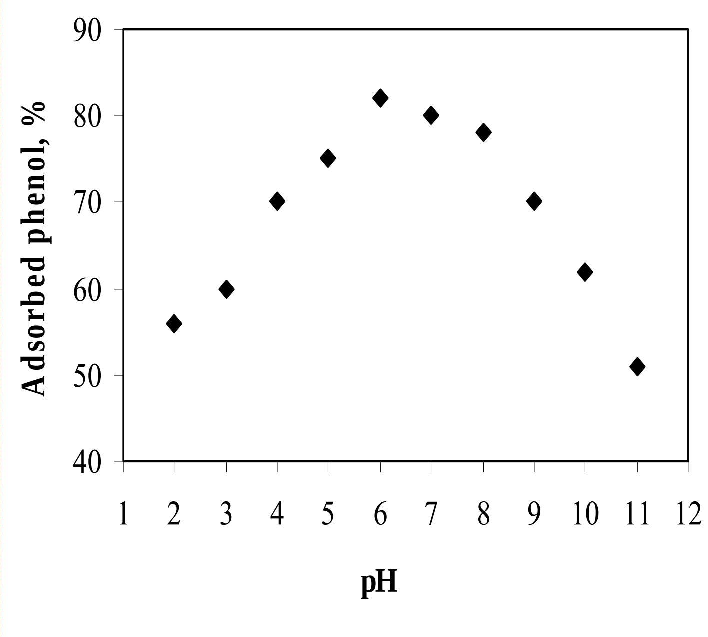
Phenol removal as function of as-grown xGnPs loading. Initial phenol concentration is 100 mg/L.



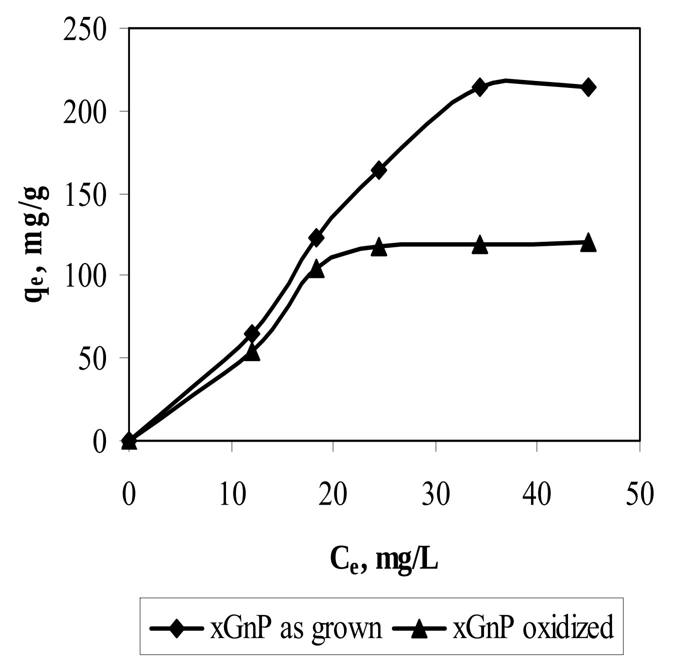
Effect of the initial phenol concentration on the adsorption of phenol on as-grown xGnPs at a loading of 125 mg/L.

A.C. Ion, A. Alpatova, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (2011) 588-595

Study on phenol adsorption from aqueous solutions on exfoliated graphitic nanoplatelets



pH effect on the phenol adsorption by as-grown xGnPs. Initial conditions: xGnP loading is 400 mg/L; initial phenol concentration is 125 mg/L.



Adsorption isotherms of phenol on as-grown and oxidized xGnP. Initial conditions: xGnPs loading 400 mg/L; initial phenol

A.C. Ion, A. Alpatova, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (2011) 588-595

Study on phenol adsorption from aqueous solutions on exfoliated graphitic nanoplatelets

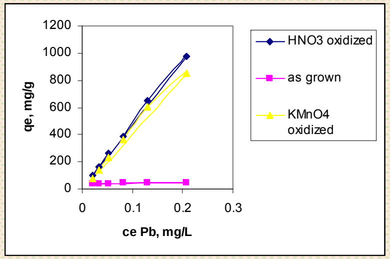
The sorption capacity of various sorbents for phenol at optimum pH values

Sorbent	Phenol, q_e, mg/g
Activated carbon	720
Activated sludge	236.8
Fly ash	3.85
S. muticum	4.6
Rice husk	42.2
Bentonite	1.712
Present work	702

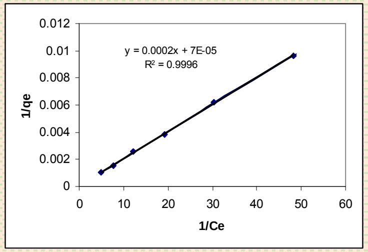
A.C. Ion, A. Alpatova, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (2011) 588-595

Lead adsorption onto exfoliated graphite nanoplatelets in aqueous solutions

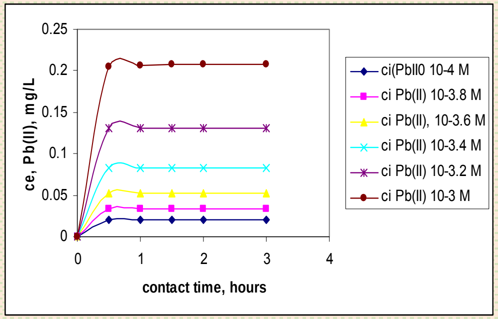
- Preliminary results regarding the sorption behaviour of Pb(II) onto exfoliated graphite nanoplatelets (xGnPs) are presented in this study.
- xGnPs present good sorption capability of Pb(II) from aqueous solution after an oxidation treatment with HNO3, the sorption properties depending on the pH value of the solutions and on the presence of active sites and the size of the surfaces



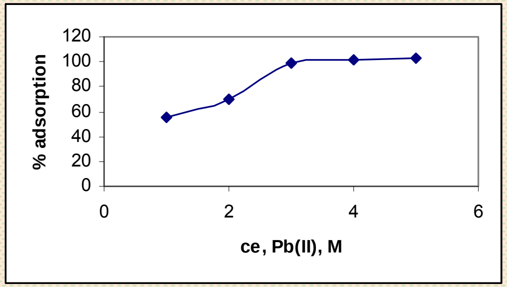
Effect of pre-treatment of xGnPs on the % removal of Pb(II) from aqueous solutions



Langmuir-2 plot for the adsorption
of Pb(II) by xGnPs



Effect of the contact time on Pb(II) adsorption rate for different concentration



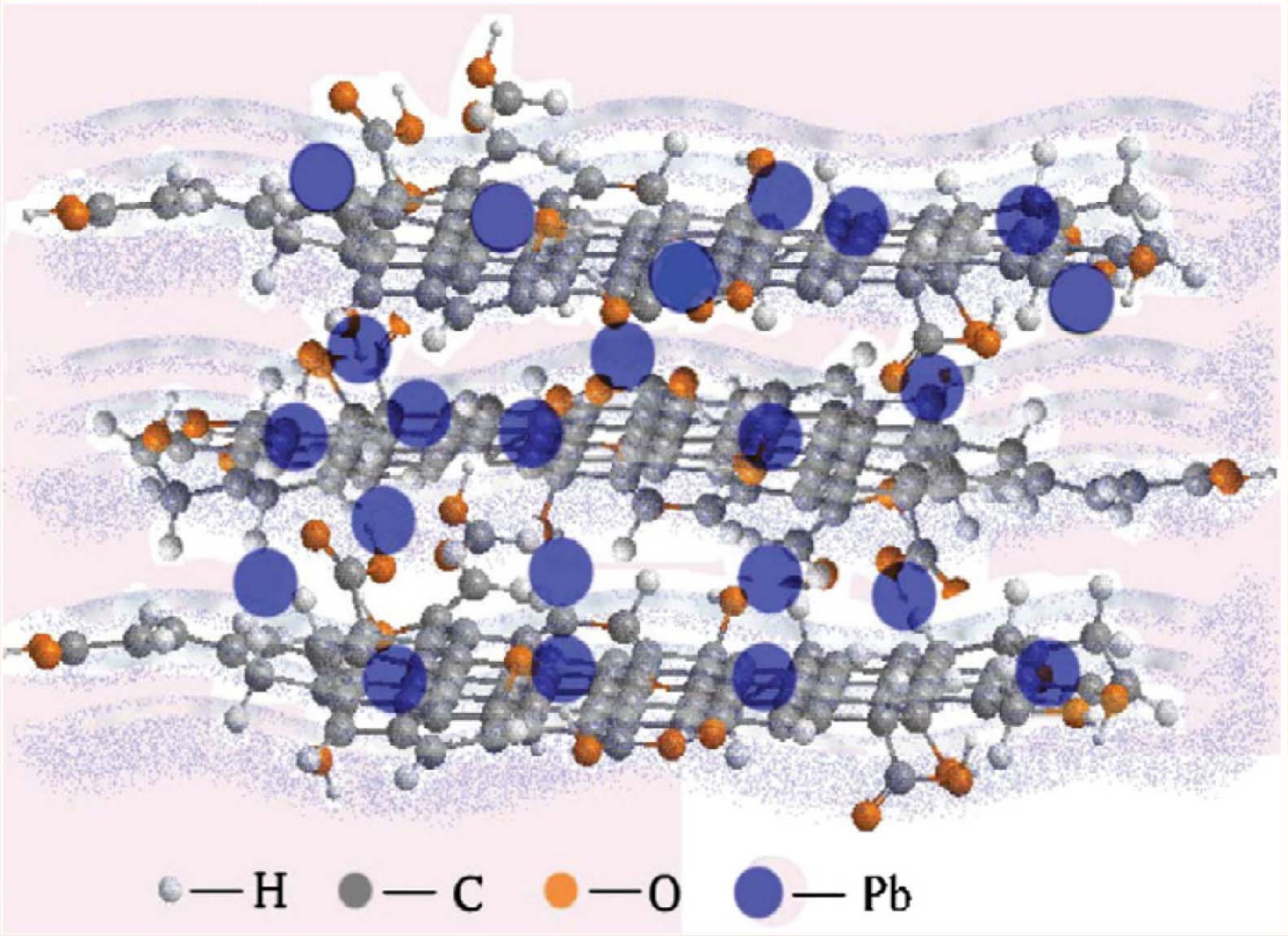
Effect of the adsorbent concentration on the adsorption of Pb(II)

Langmuir-2 constants		Freundlich constants	
q_m (mg/g)	333.3	K_F	13.592
K_a (L/mg)	0.003	n	1.142
R^2	0.9998	R^2	0.9999

Parameters of Freundlich and Langmuir-2 adsorption isotherm models for Pb(II) on xGnPs

A. C. Ion, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (6) (2011) 504-509

A schematic diagram of the formation of the surface complexes of Pb(II) ions on the surfaces of GO



Formation of surface complexes of metal ions with oxygen functional groups on graphene oxide (GO)

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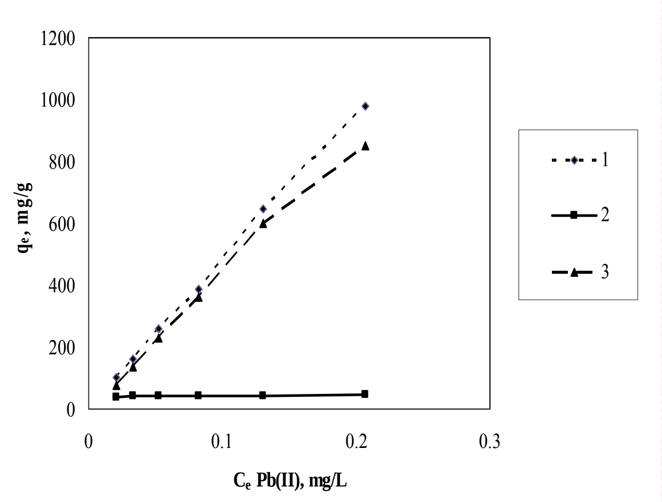
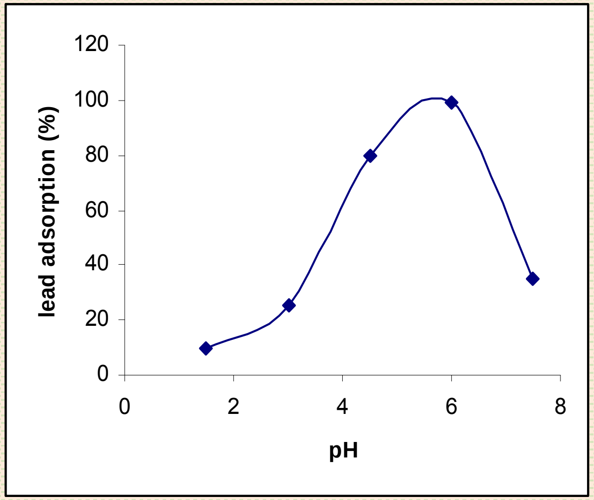
Study on lead adsorption from aqueous solutions on oxidized exfoliated graphite nanoplatelets



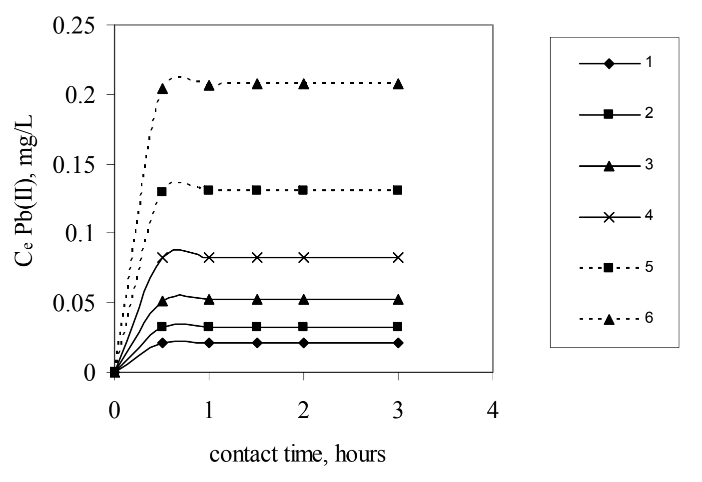
Effect of pre-treatment of xGnPs on the % removal of Pb(II) from aqueous solutions; (1) HNO3 oxidized, (2) as grown, (3) KMnO4 oxidized



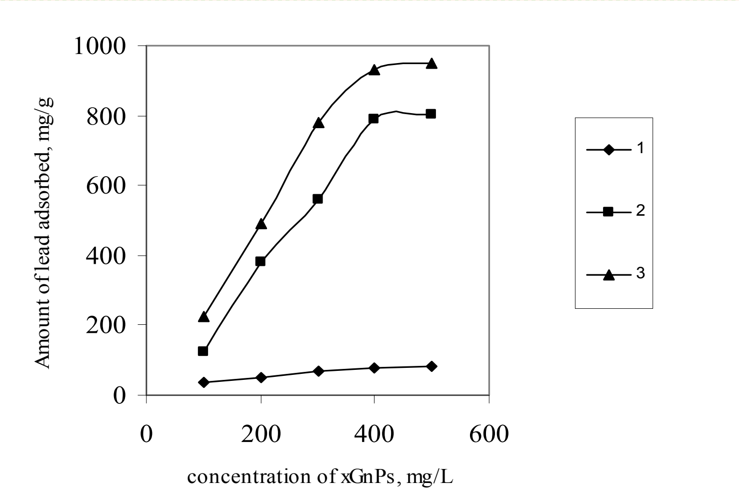
Effect of the pH on the uptake of lead; conditions: contact time 120 minutes, xGnPs concentration 400 mg/L, pH between 1.5 and 7.5

A. C. Ion, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (6) (2011) 504-509

Study on lead adsorption from aqueous solutions on oxidized exfoliated graphite nanoplatelets



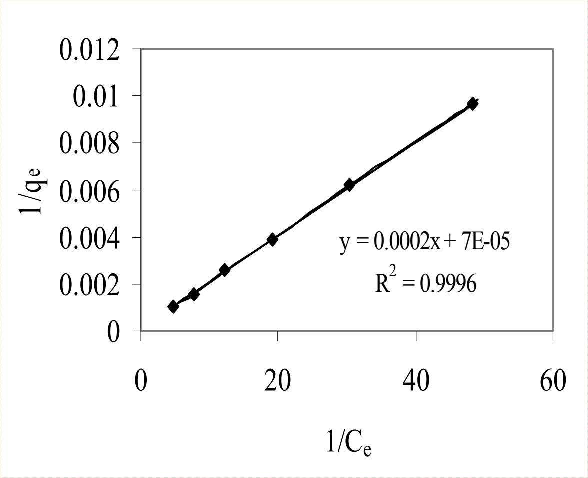
Effect of the contact time on Pb(II) adsorption rate for different concentrations (1) 10-4 M, (2) 10-3.8 M, (3) 10-3.6 M, (4) 10-3.4 M, (5) 10-3.2 M, (6) 10-3 M Pb(II)), pH=6, T=298 K, xGnPs oxidized with concentrated HNO3



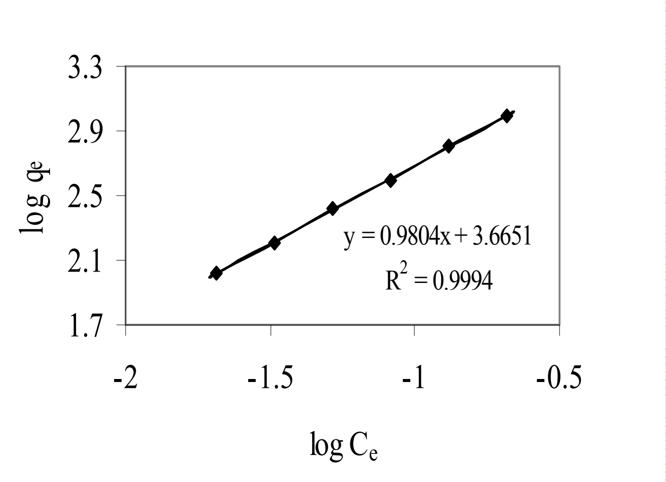
Effect of the adsorbent concentration on the adsorption of Pb(II); (1) as grown, (2) KMnO4 oxidized, (3) HNO3 oxidized; pH = 6; adsorbent concentration 200 mg/L; contact time 60 minutes

A. C. Ion, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (6) (2011) 504-509

Study on lead adsorption from aqueous solutions on oxidized exfoliated graphite nanoplatelets



Linearized Freundlich isotherms for Pb(II) adsorption by xGnPs at T=298 K



Langmuir plot for the adsorption of Pb(II) by xGnPs: pH = 6.0, adsorbent concentration 400 mg/L, contact time 30 minutes

Langmuir constants		Freundlich constants	
q_m (mg/g)	333.3	K_F	13.592
K_a (L/mg)	0.003	n	1.142
r^2	0.9994	r^2	0.9996

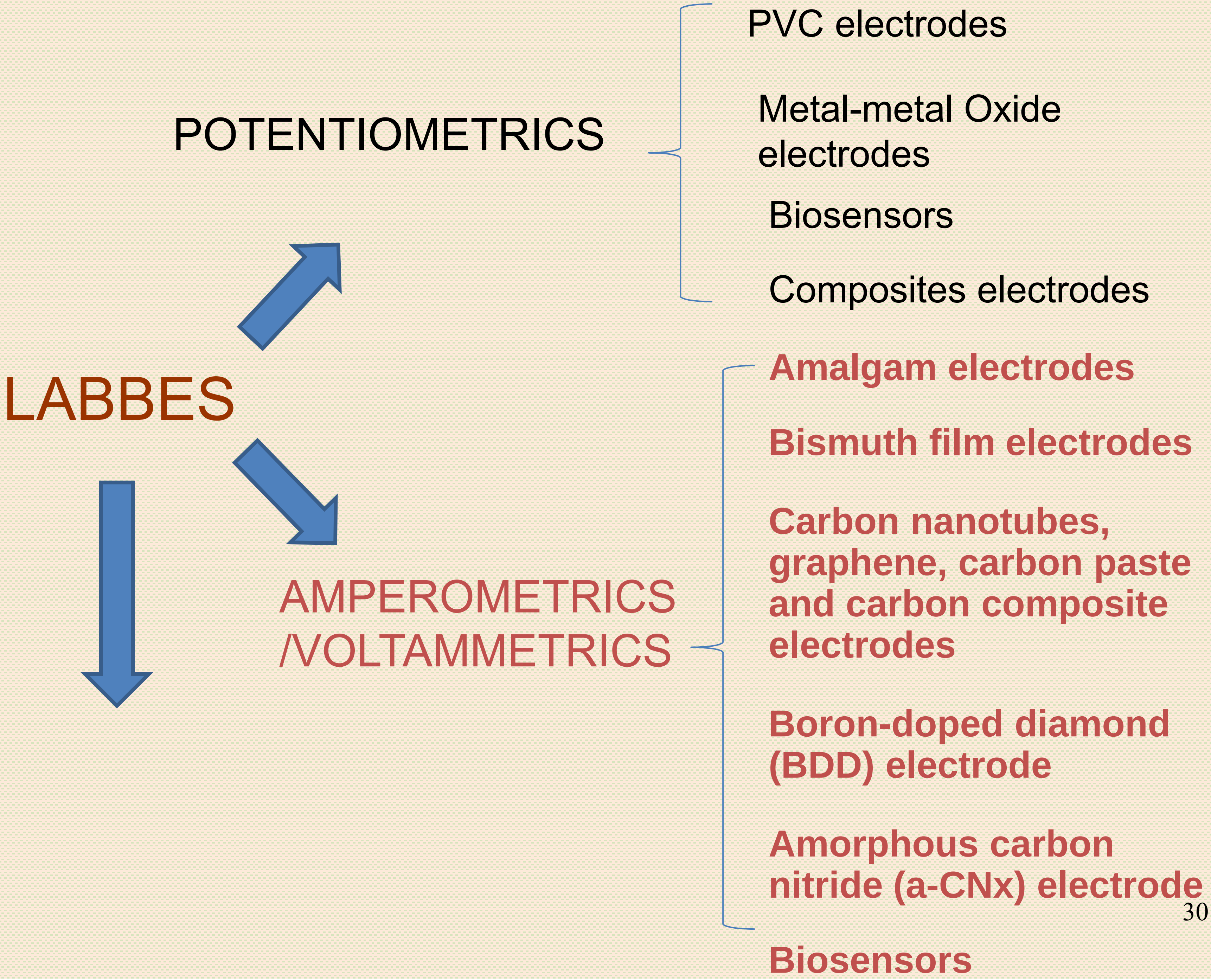
Parameters of Freundlich and Langmuir adsorption isotherm models for Pb(II) on xGnPs

A. C. Ion, I. Ion, A. Culetu, Mater. Sci. Eng. B 176 (6) (2011) 504-509

Applications of different graphene-based materials in the removal of pollutants

Graphene-base materials	Morphology	Properties	Ref.
Layers of graphene sheets	Overlapped and mesoporous	Adsorption of fluoride	40
Graphene oxide	Few layers nanosheets	Adsorption of Pb(II) ions	42
Ionic liquid functionalized graphene	Graphene thin films	Removal pf Pb(II) and Cd(II) from wastewater	44
Sulfonated graphene	Few layered nanosheets	Removal of naphthalene from waters	45
ZnO/graphene composites	ZnO nanoparticles on reduced graphene oxide sheets	Photocatalytic degradation and filtered removal of organic dyes	53
Magnetic graphene hybrids	Fe_3O_4 nanoparticles on reduced graphene oxide sheets	Arsenic removal	50
Graphene-based photothermal agent for rapid killing of bacteria	Magnetic reduced graphene oxide functionalized with glutaraldehyde	Escherichia Coli	51

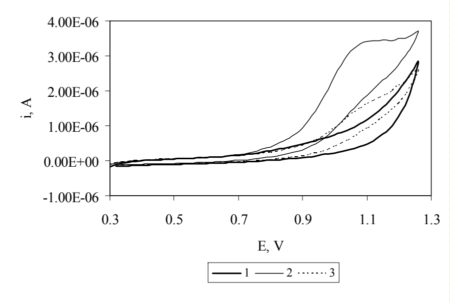
Lu Kui et al., Chinese Sci. Bull. 2012, 57(11), 1223-1234



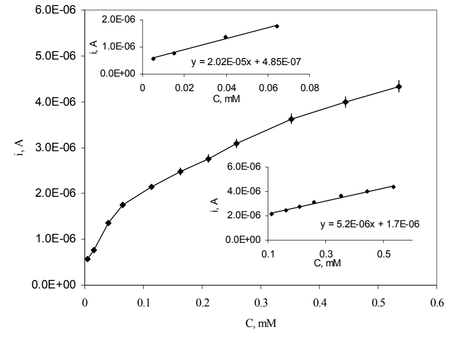
LABBES

- POTENTIOMETRICS
  - PVC electrodes
  - Metal-metal Oxide electrodes
  - Biosensors
  - Composites electrodes
- AMPEROMETRICS /VOLTAMMETRICS
  - **Amalgam electrodes**
  - **Bismuth film electrodes**
  - **Carbon nanotubes, graphene, carbon paste and carbon composite electrodes**
  - **Boron-doped diamond (BDD) electrode**
  - **Amorphous carbon nitride (a-CNx) electrode**
  - **Biosensors**

Biosensors based on carbon-nanostructures for environmental contaminants

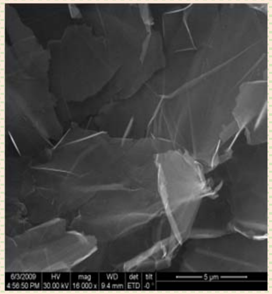


Cyclic voltammograms: AChE – chitosan modified-GCE in pH 7.4 phosphate buffer; scan rate 100 mVs-1 (1) chitosan-GCE in 0.01 M phosphate buffer pH 7.4;(2) AChE-xGnP-chitosan modified-GCE+ 0.250 mM ATCI; (3) AChE-chitosan modified-GCE without xGNP + 0.250 mM ATCI



Calibration plot of the voltammetric response of AChE-chitosam modified GCE electrode towards ATCl.

A sensitive biosensor for chloropyrifos (CPF), an organophosphorus pesticide, was developed by immobilizing acetylcholinesterase (AChE) through covalent bonding to an oxidized exfoliated graphite nanoplatelets (xGnPs) – chitosan cross-linked composite.. The response of the sensor was a linear function of ATCI concentration in two segments, one from 0.005 - 0.039 mM and the second from 0.064 mM to 0.258 mM. The corresponding equation for the first range was ip(A) = 2.26x10-5 c + 4.39x10-7 (R2 = 0.992) and the equation for the second was ip(A) = 6.80x10-6 c + 1.30x10-6 (R2 = 1.000), with a detection limit of 1.58x10-10 M. The fabrication of the sensor was simple, the response was fast and the stability acceptable. This sensor has many potential applications, the foremost being in organophosphorus pesticides.



FEG SEM images of the dispersed oxidized xGnP in chitosan

Inhibition	Enzyme	Technique	Sample	LOD	Ref.
CPF	AChE	Voltammetric	Wine	< 300 ng mL^{-1}	[i]
CPF	BChE	Voltammetric	Grape juice	$2x10^{-8}$ M	[ii]
CPF	AChE	Voltammetric	Aqueous samples	$3x10^{-8}$ M	[iii]
CPF	AChE	Voltammetric	Aqueous samples	$1.58x10^{-10}$ M	This work

A.C. Ion, I.Ion, A. Culetu, D. Gherase, C. Moldovan, A. Dinescu, Mater. Sci. Eng. C (2010), 30(6), 817-821

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[i] M. Del Carlo, M. Mascini, A. Pepe, D. Compagnone, J. Agric. Food Chem., 2002, 50, 7206-7210

[ii] A. Ivanov, G. Evtugyn, H. C. Budnikov, F. Ricci, D. Moscone, G. Palleschi, Anal. Bioanal. Chem., 2003, 377, 624-631

[iii] E. V. Suprun, H. C. Budnikov, G. A. Evtugyn, Kh. Z. Brainina, Bioelectrochemistry, 2004, 63(1-2), 281-284

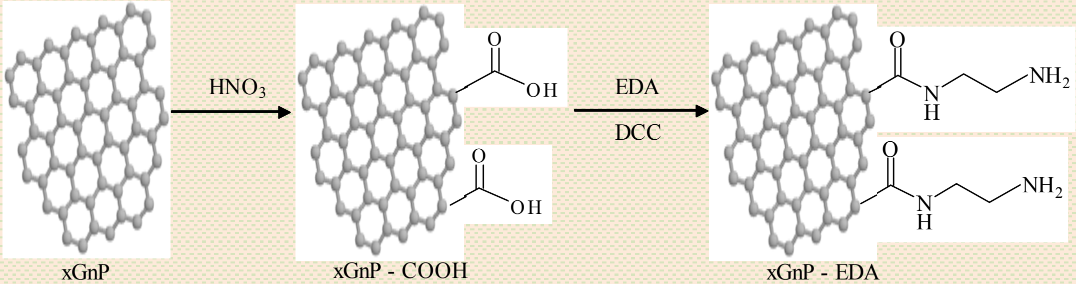
Comparative analysis of organophosphate pesticides in broccoli and cabbage using the proposed biosensor and chromatographic methods

Probe de brocoli	Chlorpyriphos mg kg^{-1} (Cromatografic)	Clorpirifos mg kg^{-1} (Biosenzor cu AchE)
1	0.022	0.020
2	0.020	0.015
3	0.013	0.010
4	< LOQ	< LOQ
5	< LOQ	< LOQ

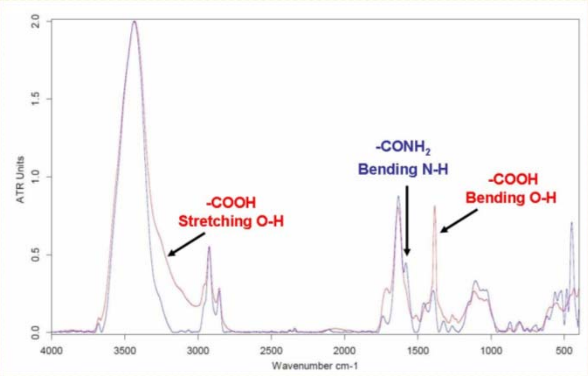
Probe de varza	Clorpirifos mg kg^{-1} (Cromatografic)	Clorpirifos mg kg^{-1} Biosenzor cu AChE
1	0.022	0.020
2	0.020	0.015
3	0.013	0.010

I. Ion, Alina C. Ion, Mater. Sci.Eng. C, 2012, 32(4), 1001-1004

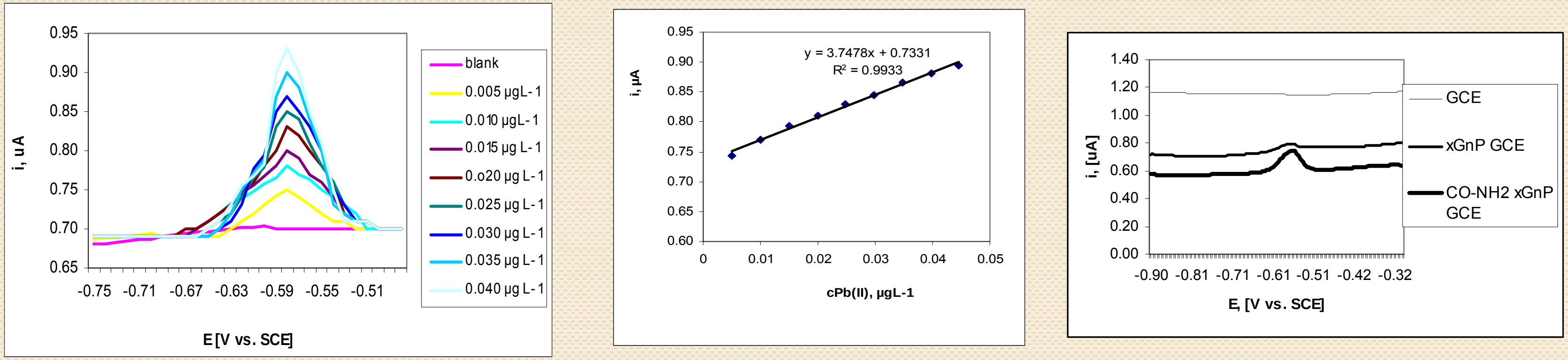
Differential pulse voltammetric analysis of lead in vegetables using a surface amino-functionalized exfoliated graphite nanoplatelet chemically modified electrode



Functionalization of the exfoliated graphite nanoplatelet (xGnP) with amide groups



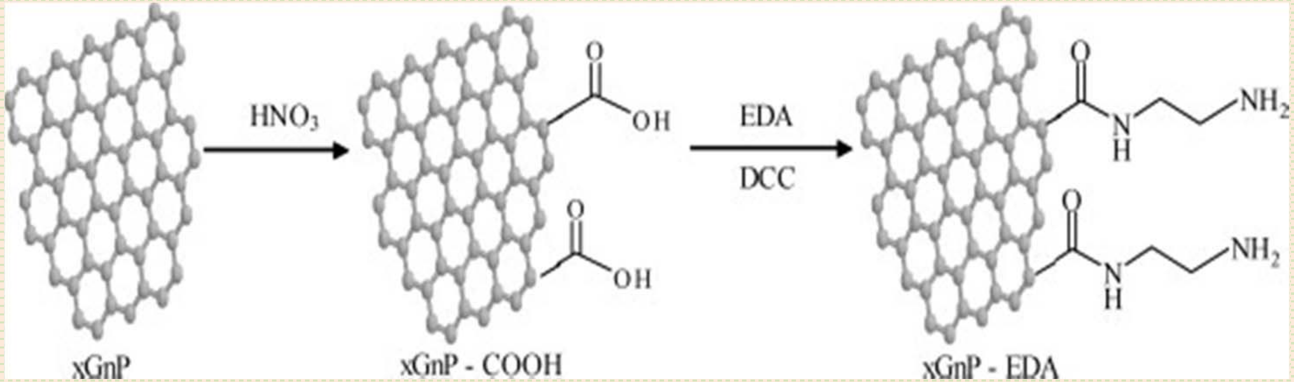
FTIR spectra of oxidized (-) and of amino-functionalized (-CO-NH2)
(-)exfoliated graphite nanoplatelet (xGnP)



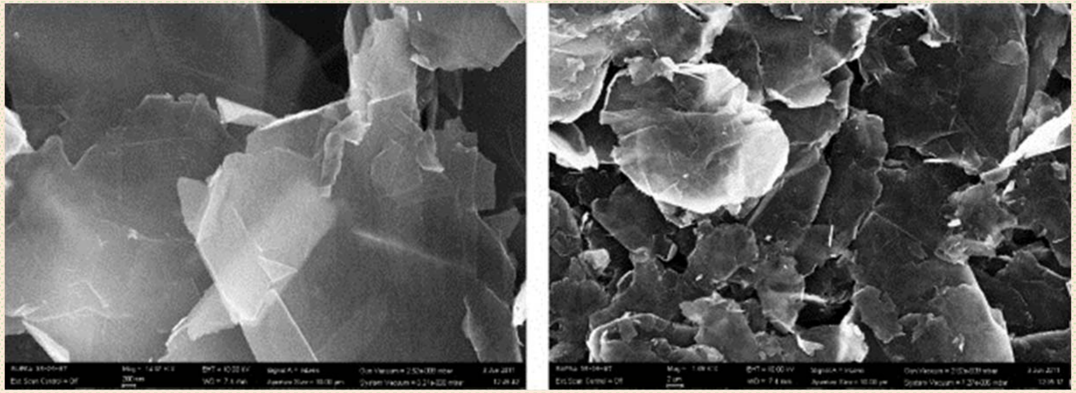
DPV for different concentrations of Pb(II) at the Bi film amino-functionalized (-CO-NH2) exfoliated graphite nanoplatelet (xGnP)/GCE modified electrode in 0.01 M phosphate buffer pH 4.5 in the range of Pb(II) concentrations between 0.005 – 0.045 μg L-1, y=3.75x + 0.73, R2 = 0.9933

I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

Functionalization of the exfoliated graphite nanoplatelet (xGnP) with amide groups

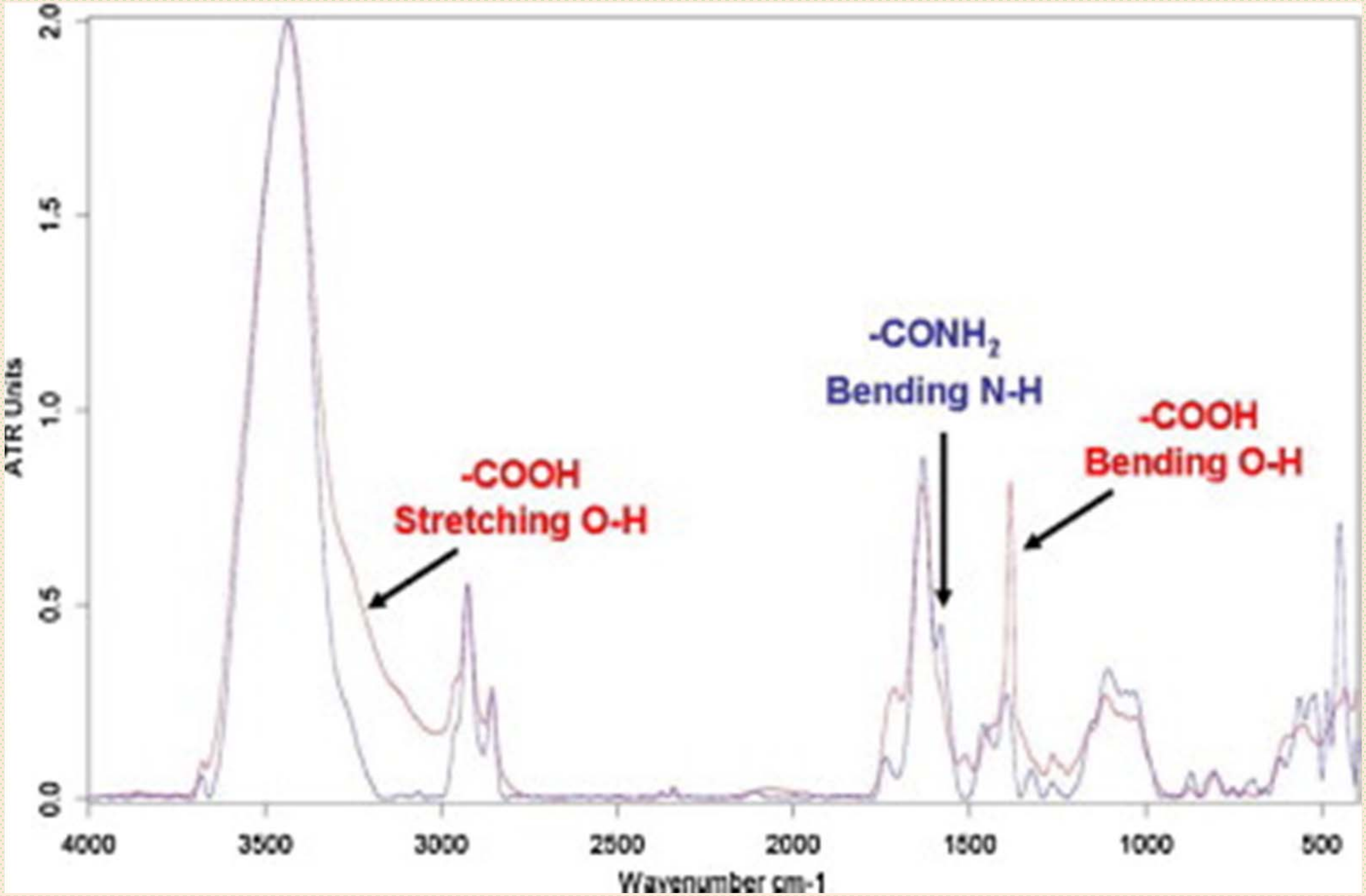


SEM image of the as grown xGnP and of the amino-functionalized and (-CONH$_2$) exfoliated graphite nanoplatelets (xGnPs)



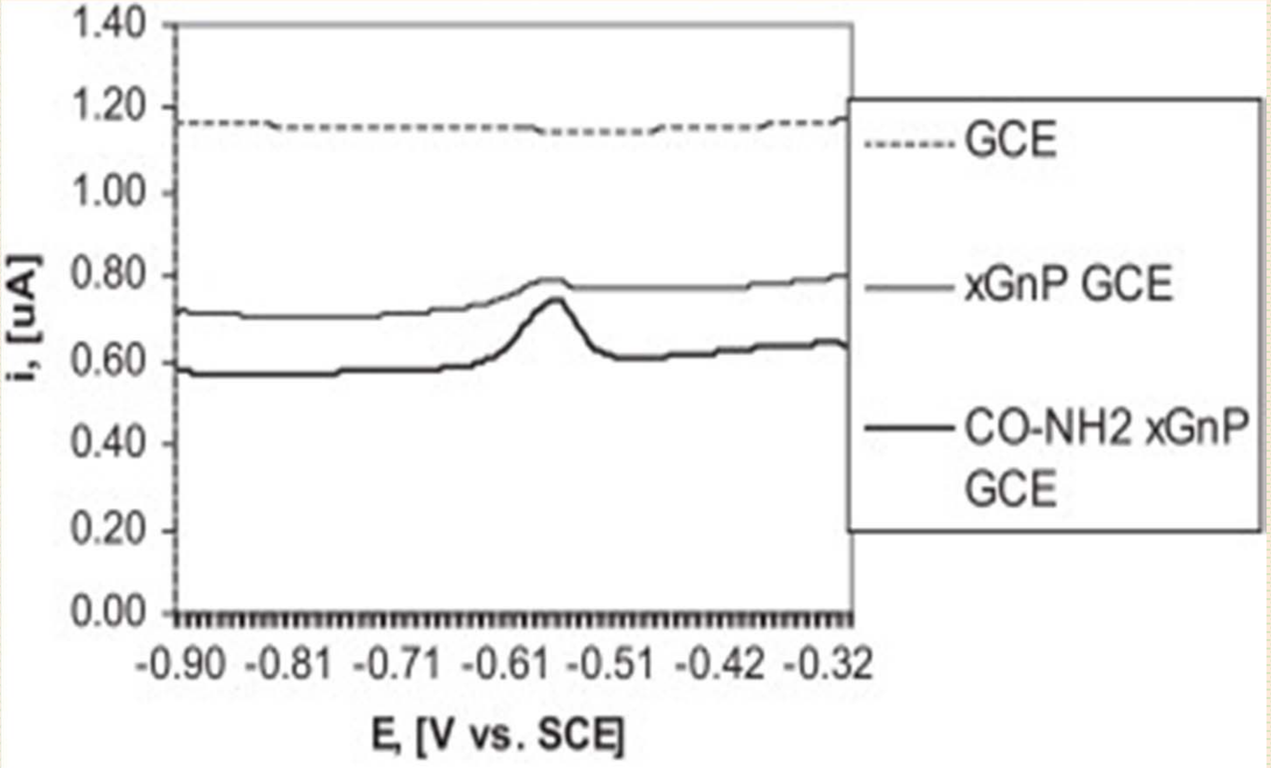
I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

FTIR spectra of oxidized (____) and of amino-functionalized (-CONH$_2$) and (____) exfoliated graphite nanoplatelet (xGnP).



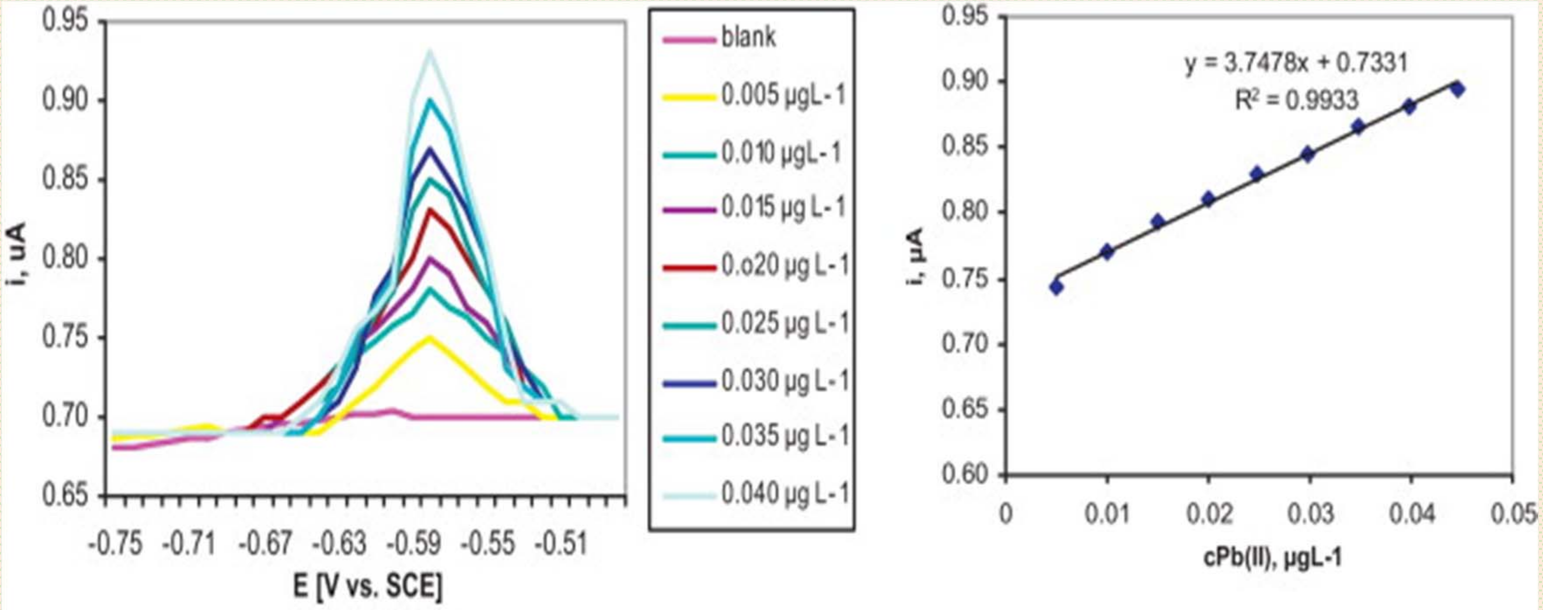
I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

Bismuth films on (1) GCE; (2) GCE modified with xGnP; (3) GCE modified with amino-functionalized (-CONH$_2$) exfoliated graphite nanoplatelet (xGnP) 30 μg L^{-1} Pb(II) in 0.1 M phosphate buffer (pH = 4.5), scan rate 100 mV s^{-1}.



I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

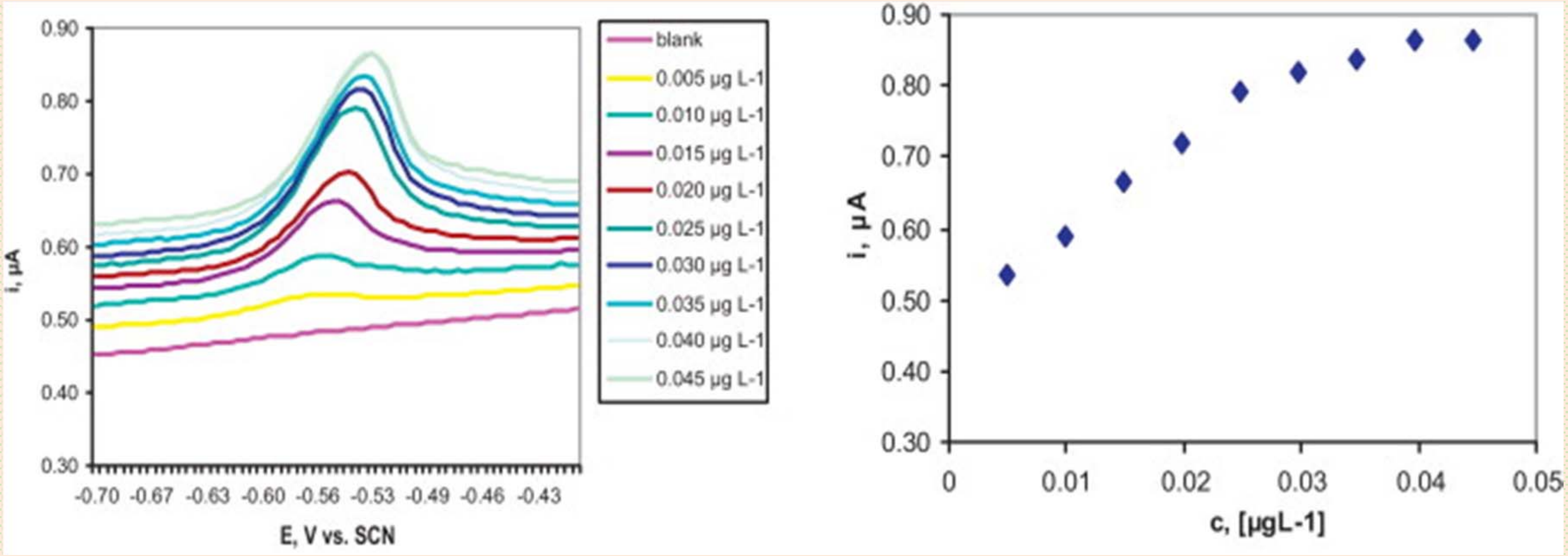
DPV for different concentrations of Pb(II) at the Bi film amino-functionalized ($-CONH_2$) exfoliated graphite nanoplatelet (xGnP)/GCE modified electrode in 0.01 M phosphate buffer pH 4.5 in the range of Pb(II) concentrations between 0.005 and 0.045 $\mu g\ L^{-1}$, $y = 3.75x + 0.73$, $R^2 = 0.9933$



I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

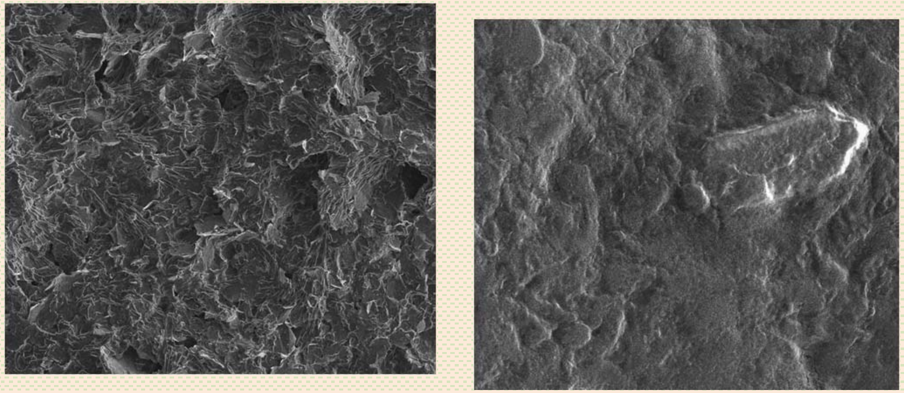
DPV measurements in vegetables (cabbage juice) for Pb(II)

- using the Bi amino-functionalized (-$CONH_2$) exfoliated graphite nanoplatelet (xGnP)/GE electrode in acetate buffer solution (pH = 4.5) in the concentrations range 0.005– 0.035 µg L^{-1}, with the correspondent equations of regression: $y = 13.06x + 0.46$, $R^2 = 0.9970$.

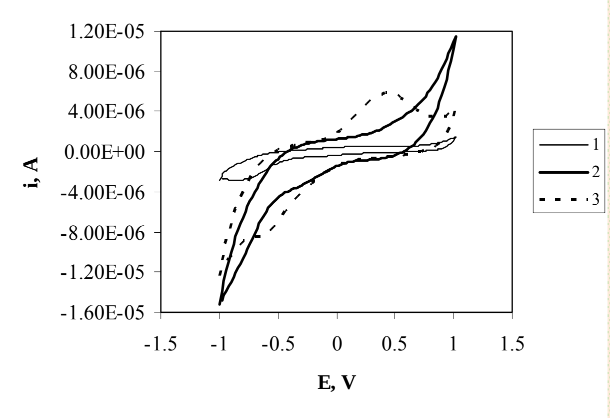


I. Ion, Alina C. Ion, Sensors and Actuators, B: Chemical 2012, 166-167, 842-847

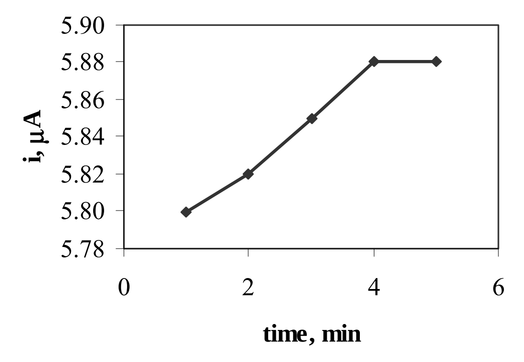
Application of an exfoliated graphite nanoplatelet –modified electrode for the determination of quintozen



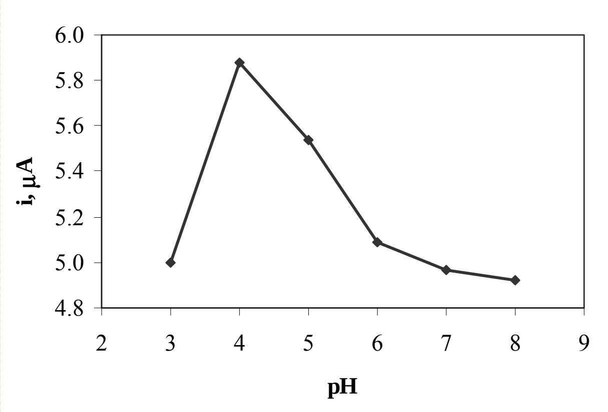
FEG-SEM (field emission gun scanning electron microscopy) images of xGnP in DMF and the dispersed xGnPs and chitosan in DMF solvent



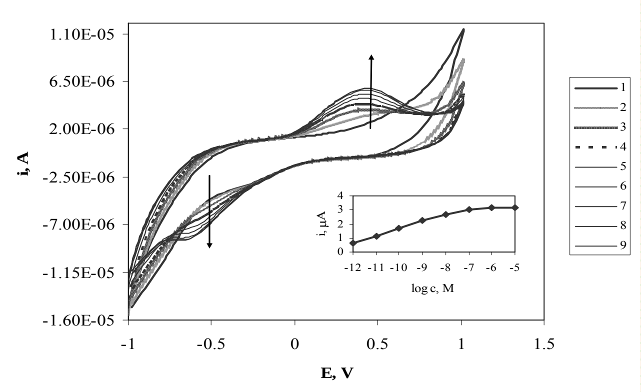
Cyclic voltammograms of xGnP-chit/GCE modified electrode in 0.01 M phosphate buffer pH 4 for: the GC electrode in 0.01 M phosphate buffer pH 4 (1) xGnP-Chit/GC modified electrode in PBS pH 4 (2) and for xGnP-Chit/GC modified electrode in PBS pH 4 at a 10-5 M concentration of quintozen (3)



Effect of pre-concentration time on the differential pulse response of the adsorbed quintozen (the concentration of quintozen 10-5 M)



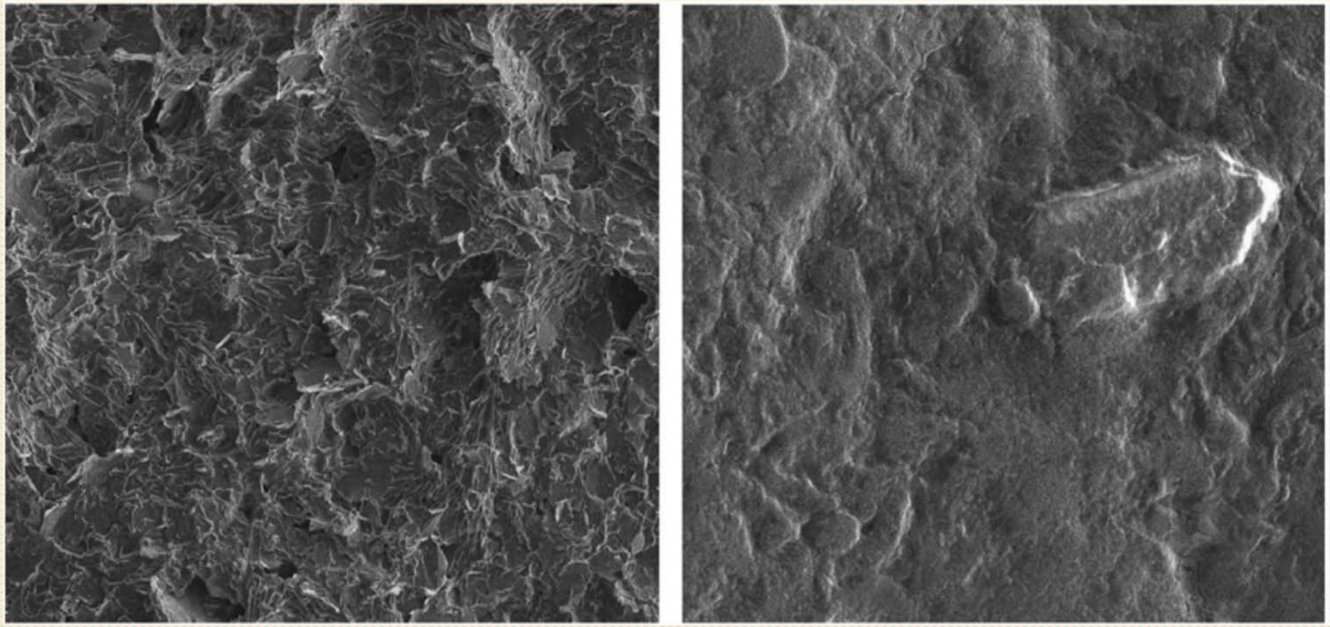
Effect of the pH of the adsorption medium



Cyclic voltammograms on xGnP-chit/GCE modified electrode in 0.01 M phosphate buffer pH 4 for increasing concentrations of quintozen from 10-12 - 10-5 M; (1) blank, (2) – 10-12 M, (3) – 10-11 M, …(9) – 10-5 M, (12 µL of xGnP –chit/DMF the solution added on the electrode surface)

I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557

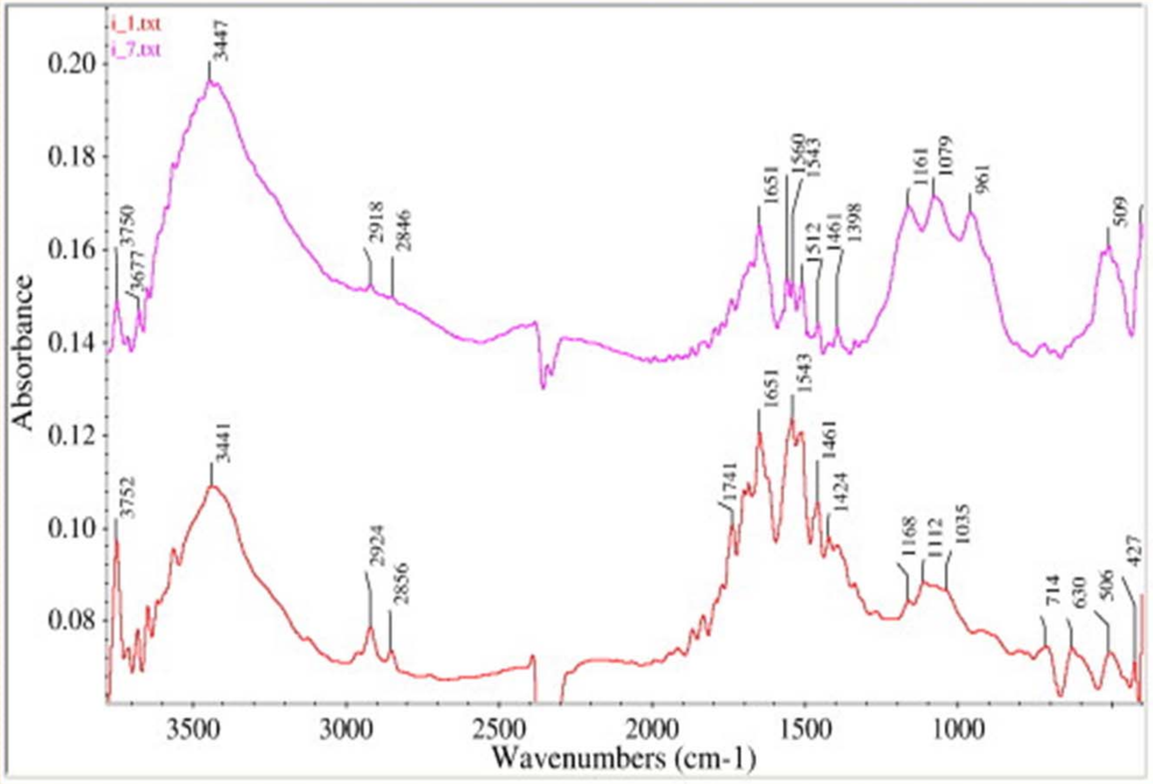
Application of an exfoliated graphite nanoplatelet-modified electrode for the determination of QUINTOZEN



FEG-SEM (field emission gun scanning electron microscopy) images of xGnP in DMF and the dispersed xGnPs and chitosan in DMF solvent.

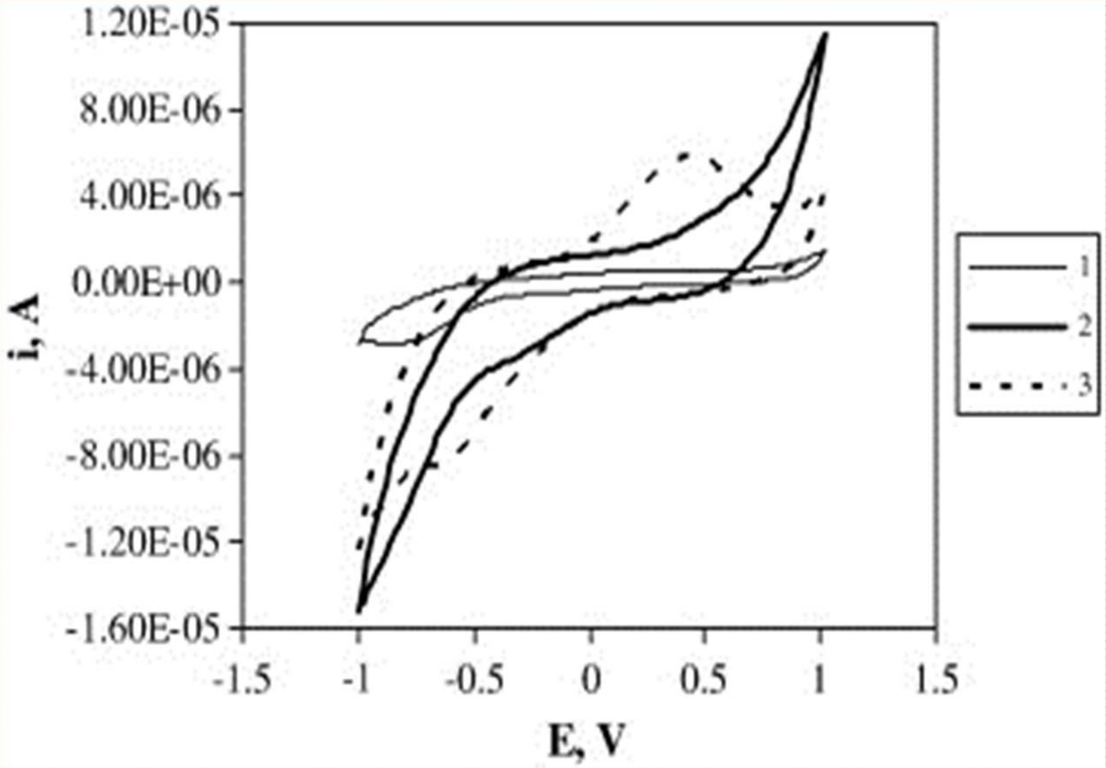
I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557

Fourier transform infrared (FTIR) spectra of as-prepared (_____) and oxidized xGnP (_____).



I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557

Cyclic voltammograms of xGnP–Chit/GCE modified electrode in 0.01 M phosphate buffer pH 4



(1) the GC electrode in 0.01 M phosphate buffer pH 4

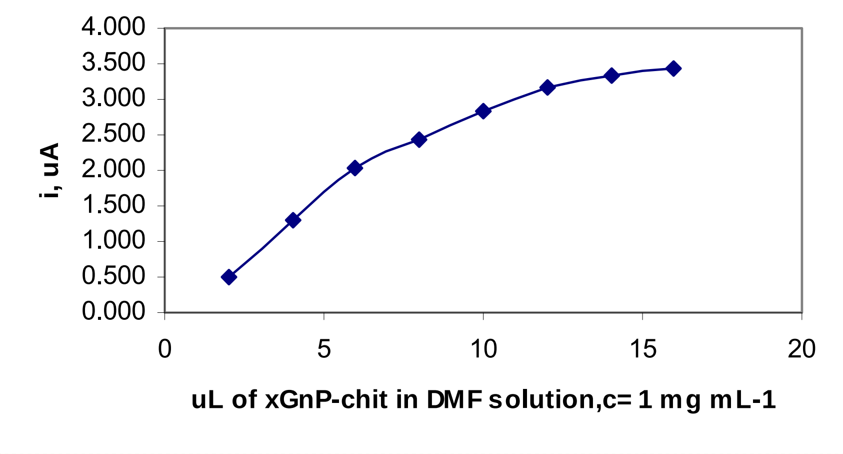
(2) xGnP–Chit/GC modified electrode in PBS pH 4

(3) for xGnP–Chit/GC modified electrode in PBS pH 4 at a 10^{-5} M concentration of quintozen.

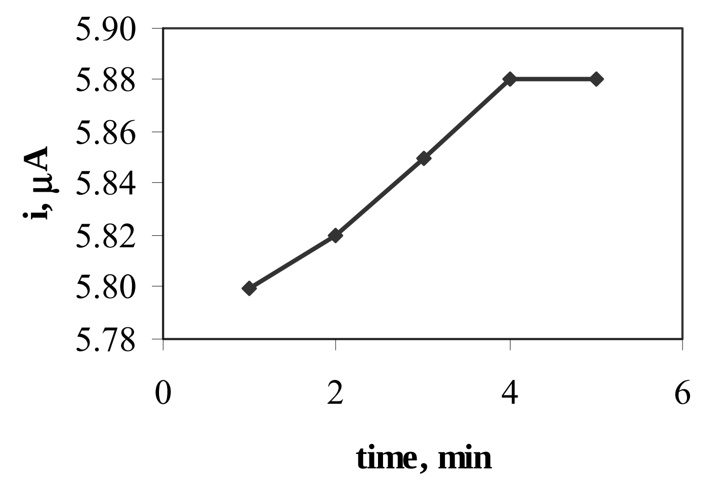
I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557

Influence of different parameters on the response of the sensor

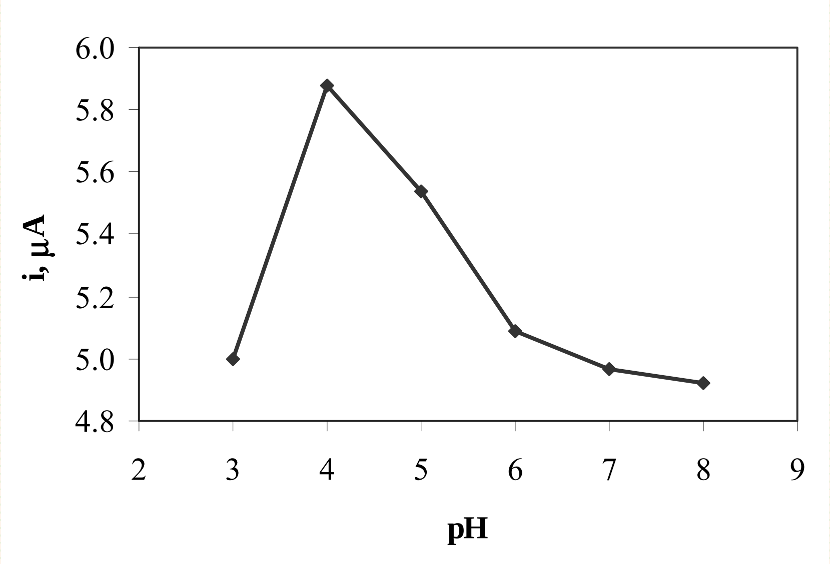
Effect of the concentration of xGnP on a delimited electrode surface



Effect of pre-concentration time on the differential pulse response of the adsorbed quintozen (the concentration of quintozen 10^{-5} M)

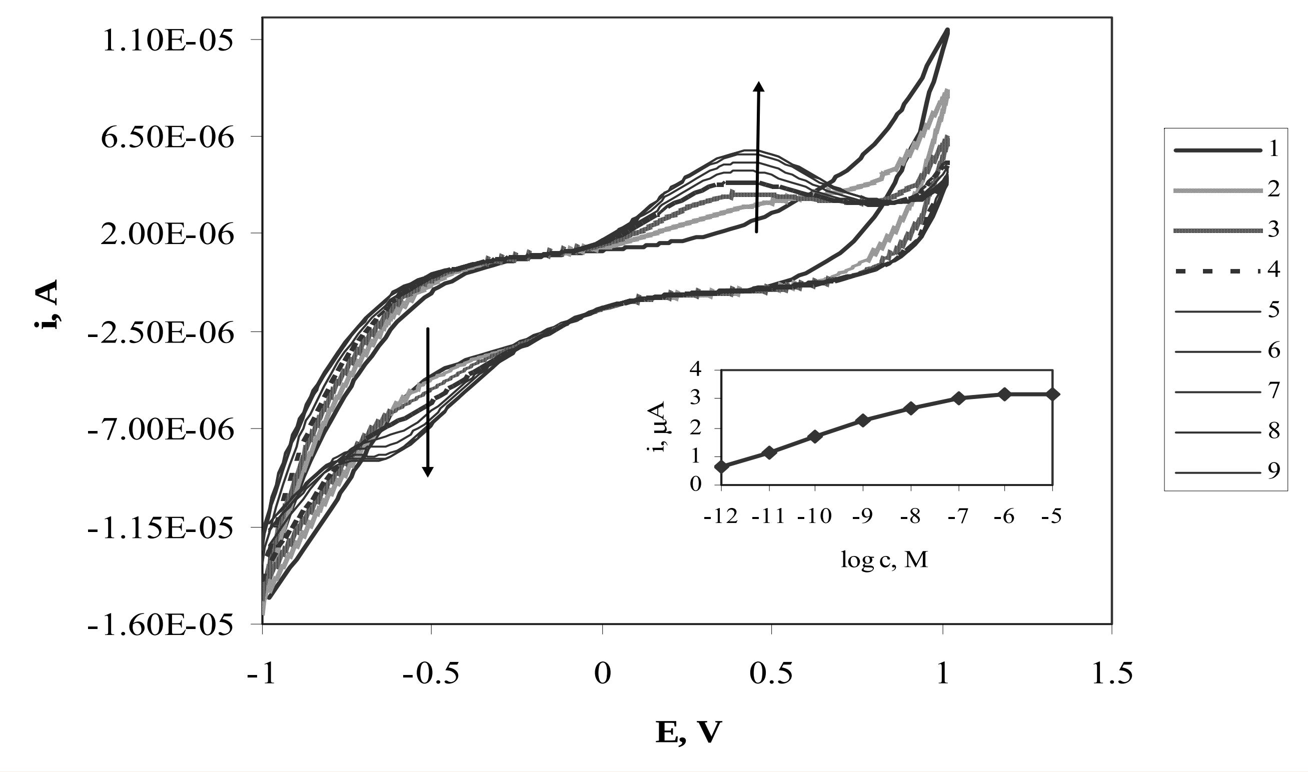


Effect of the pH of the adsorption medium



I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557

Cyclic voltammograms on xGnP-chit/GCE modified electrode in 0.01 M phosphate buffer pH 4



(1) blank

(2) – 10^{-12} M

(3) – 10^{-11} M

…

(9) – 10^{-5} M

(12 µL of xGnP – chit/DMF the solution added on the electrode surface)

I. Ion, Alina C. Ion, Alina Culetu, Mater. Sci. Eng. C 2011, 31(7), 1553-1557