

The Analyst

Interdisciplinary detection science

www.rsc.org/analyst

RSC Publishing is a not-for-profit publisher and a division of the Royal Society of Chemistry. Any surplus made is used to support charitable activities aimed at advancing the chemical sciences. Full details are available from www.rsc.org

IN THIS ISSUE

ISSN 0003-2654 CODEN ANALAO 133(4) 405-544 (2008)

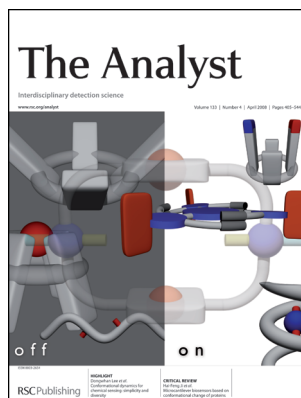


Cover

See X. Ye, S. S. Rubakhin and J. V. Sweedler, pp. 423–433.

The cover shows sensing nitric oxide production in individual PC12 cells with fluorescence microscopy and single cell capillary electrophoresis.

Image reproduced by permission of Jonathan V. Sweedler from *Analyst*, 2008, **133**, 423.



Inside cover

See J. A. Riddle, X. Jiang and D. Lee, pp. 417–422.

A schematic rendition showing analyte-induced structural transition of selected shape-adaptive chemical sensors. Molecular symmetry simplifies the energy landscape of conformational switching, which serves as the key signal transduction mechanism shared by these dynamic constructs.

Image reproduced by permission of Dongwhan Lee from *Analyst*, 2008, **133**, 417.

CHEMICAL TECHNOLOGY

T25

Drawing together research highlights and news from all RSC publications, *Chemical Technology* provides a 'snapshot' of the latest applications and technological aspects of research across the chemical sciences, showcasing newsworthy articles and significant scientific advances.

Chemical Technology

April 2008/Volume 5/Issue 4

www.rsc.org/chemicaltechnology

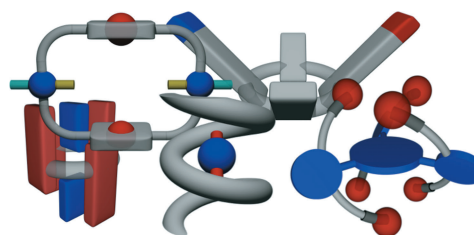
i-SECTION: HIGHLIGHT

417

Conformational dynamics for chemical sensing: simplicity and diversity

Justin A. Riddle, Xuan Jiang and Dongwhan Lee*

Conformational switching of ingeniously designed chemical architectures can directly couple analyte-induced structural distortions to sensory signaling events.



EDITORIAL STAFF

Editor

Niamh O'Connor

Deputy editor

May Copsey

Assistant editors

Nina Notman

Publishing assistant

Linda Warncke

Team leader, serials production

Stephen Wilkes

Technical editor

Susan Askey

Production administration coordinator

Sonya Spring

Administration assistants

Clare Davies, Donna Fordham, Kirsty Lunnon,
Julie Thompson

Publisher

Graham McCann

The Analyst (print: ISSN 0003-2654; electronic: ISSN 1364-5528) is published 12 times a year by the Royal Society of Chemistry, Thomas Graham House, Science Park, Milton Road, Cambridge, UK, CB4 0WF.

All orders, with cheques made payable to the Royal Society of Chemistry, should be sent to RSC Distribution Services, c/o Portland Customer Services, Commerce Way, Colchester, Essex, UK CO2 8HP. Tel +44 (0) 1206 226050; E-mail sales@rscdistribution.org

2008 Annual (print + electronic) subscription price: £1200; US\$2388. 2008 Annual (electronic) subscription price: £1080; US\$2149. Customers in Canada will be subject to a surcharge to cover GST. Customers in the EU subscribing to the electronic version only will be charged VAT.

If you take an institutional subscription to any RSC journal you are entitled to free, site-wide web access to that journal. You can arrange access via Internet Protocol (IP) address at www.rsc.org/ip. Customers should make payments by cheque in sterling payable on a UK clearing bank or in US dollars payable on a US clearing bank. Periodicals postage paid at Rahway, NJ, USA, and at additional mailing offices. Air freight and mailing in the USA by Mercury Airfreight International Ltd., 365 Blair Road, Avenel, NJ 07001, USA.

US Postmaster: Send address changes to: The Analyst, c/o Mercury Airfreight International Ltd., 365 Blair Road, Avenel, NJ 07001. All despatches outside the UK by Consolidated Airfreight.

PRINTED IN THE UK

Advertisement sales:

Tel +44 (0) 1223 432246;
Fax +44 (0) 1223 426017;
E-mail advertising@rsc.org

The Analyst

Interdisciplinary detection science

www.rsc.org/analyst

The Analyst publishes cutting edge interdisciplinary research that presents a significant advance in fundamental theory, practice or application of (bio)analytical and detection science, including the detection, identification and quantification of chemical, biochemical and biomedical species and events; novel approaches to the study of atomic and molecular species and the development of new technologies to detect and gain chemical information with greater speed, throughput and sensitivity.

EDITORIAL BOARD

Chair

Elizabeth A. H. Hall,
Cambridge, UK

Editor for the Americas

Paul W. Bohn, Notre Dame, USA

Scientific editor, i-section

Michael Thompson, Toronto,
Canada
Potential contributors wishing to discuss articles for the i-section may contact the Scientific Editor.
E-mail mikethom@chem.utoronto.ca

R. Graham Cooks, West Lafayette, USA
Volker K. Deckert, Dortmund, Germany
Duncan Graham, Glasgow, UK
José M. Pingarrón, Madrid, Spain
Mengsu Yang, Hong Kong

ADVISORY BOARD

Damien Arrigan, Cork, Ireland
Dania Barceló, Barcelona, Spain
Richard G. Brereton, Bristol, UK
Luis A. Colón, Buffalo, NY, USA
Colin S. Creaser, Nottingham, UK
Dermot Diamond, Dublin, Ireland
Marcos N. Eberlin, Campinas, Brazil
Kevin A. Francesconi, Graz, Austria
Paul R. Haddad, Tasmania, Australia
Kiyokatsu Jinno, Toyohashi, Japan

Robert T. Kennedy, Ann Arbor, MI, USA
Hian-Kee Lee, Kent Ridge, Singapore
Ryszard Lobinski, Pau, France
Charles A. Lucy, Alberta, Canada
Rachel A. McKendry, London, UK
James N. Miller, Loughborough, UK
Reinhard Niessner, Munich, Germany
Francesco Palmisano, Bari, Italy
Janusz Pawliszyn, Ontario, Canada

Marja-Liisa Riekkola, Helsinki, Finland
Jaromir Ruzicka, Seattle, WA, USA
Wolfgang Schuhmann, Bochum, Germany
Steven A. Soper, Baton Rouge, LA, USA
Dana Spence, Detroit, MI, USA
Apyll Stalcup, Cincinnati, OH, USA
Karel Štulík, Prague, Czech Republic
Kemin Wang, Hunan, PR China
Ian D. Wilson, Macclesfield, UK

INFORMATION FOR AUTHORS

Full details of how to submit material for publication in The Analyst are given in the Instructions for Authors (available from <http://www.rsc.org/authors>). Submissions should be sent *via* ReSource: <http://www.rsc.org/resource>

Authors may reproduce/republish portions of their published contribution without seeking permission from the RSC, provided that any such republication is accompanied by an acknowledgement in the form: (Original Citation)—Reproduced by permission of the Royal Society of Chemistry.

© The Royal Society of Chemistry 2008. Apart from fair dealing for the purposes of research or private study for non-commercial purposes, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988 and the Copyright and Related Rights Regulations 2003, this publication may only

be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the Publishers or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency in the UK. US copyright law is applicable to users in the USA.

The Royal Society of Chemistry takes reasonable care in the preparation of this publication but does not accept liability for the consequences of any errors or omissions.

Ⓢ The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).

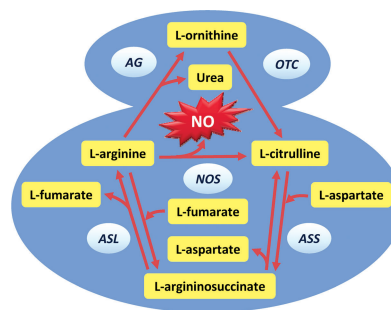
Royal Society of Chemistry:
Registered Charity No. 207890.

423

Detection of nitric oxide in single cells

Xiaoying Ye, Stanislav S. Rubakhin and Jonathan V. Sweedler*

Nitric oxide is an enigmatic cell-to-cell signaling molecule. Analytical techniques enabling nitric oxide detection at single cell levels are reviewed, including fluorescence microscopy, capillary electrophoresis, and electrochemistry.

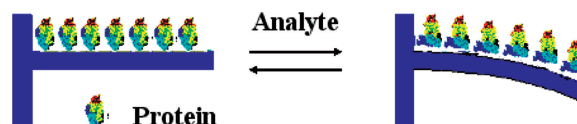


434

Microcantilever biosensors based on conformational change of proteins

Hai-Feng Ji,* Hongyan Gao, Koutilya R. Buchapudi, Xin Yang, Xiaohu Xu and Marvin K. Schulte

This review will provide an overview of microcantilever biosensors based on conformational change of proteins bound to the microcantilever surface. The models include conformational change of proteins, proteins on membranes, enzymes, DNA, and other polymers



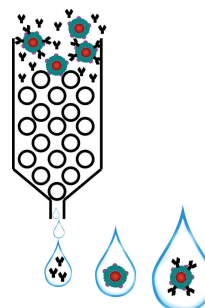
COMMUNICATIONS

444

Simple bio-conjugation of polymer-coated quantum dots with antibodies for fluorescence-based immunoassays

M. T. Fernández-Argüelles, J. M. Costa-Fernández, R. Pereiro and A. Sanz-Medel*

For the synthesis and purification of polymer-coated quantum dot-labelled antibodies, purified bio-conjugates are characterized by fluorescence emission and MALDI-TOFMS, and then evaluated in a fluorescence immunoassay for the detection of toxic aflatoxin B1.

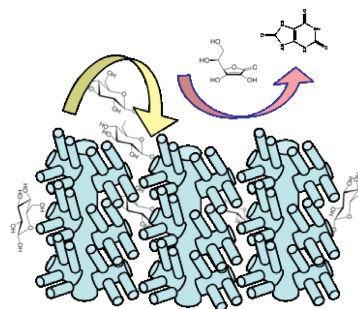


448

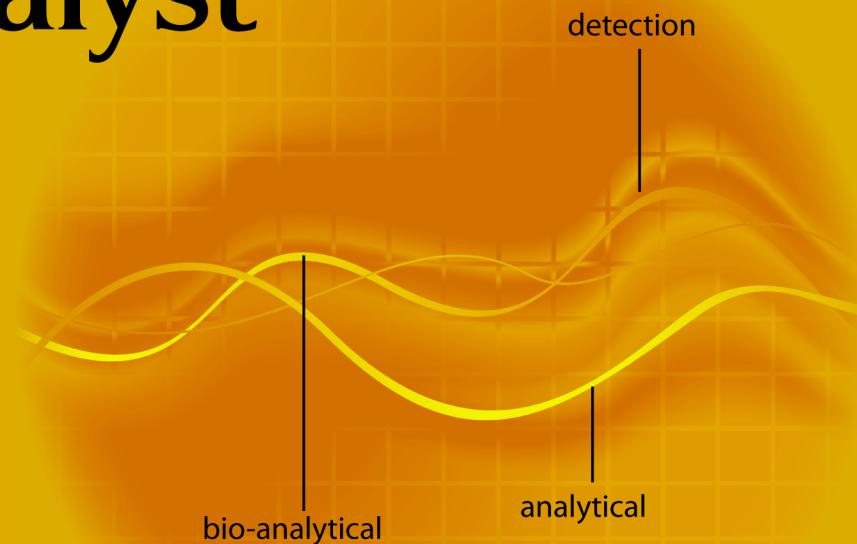
Direct amperometric detection of glucose on a multiple-branching carbon nanotube forest

Chow Khim Tan, Kian Ping Loh* and Thong T. L. John

Direct amperometric sensing of glucose has been achieved by using multiply-branched CNTs prepared by growing secondary or tertiary 'offshoot' CNTs on top of the existing CNT layer.



The Analyst



Bioanalytical Science

010850

Examples of recent articles include:

Ultrasensitive assays for proteins

Hongquan Zhang, Qiang Zhao, Xing-Fang Li and X. Chris Le

Analyst, 2007, **132**, 724 - 737, DOI: 10.1039/b704256f

Electrochemical strategies for the label-free detection of amino acids, peptides and proteins

Grégoire Herzog and Damien W. M. Arrigan

Analyst, 2007, **132**, 615 - 632, DOI: 10.1039/b701472d

Microwave-accelerated metal-enhanced fluorescence: application to detection of genomic and exosporium anthrax DNA in <30 seconds

Kadir Aslan, Yongxia Zhang, Stephen Hibbs, Les Baillie, Michael J. R. Previte and Chris D. Geddes

Analyst, 2007, **132**, 1130 - 1138, DOI: 10.1039/b707876e

Surface immobilisation and properties of smooth muscle cells monitored by on-line acoustic wave detector

Xiaomeng Wang, Jonathan S. Ellis, Chung-Dann Kan, Ren-Ke Li and Michael Thompson

Analyst, 2008, **133**, 85 - 92, DOI: 10.1039/b714210b

Protein-nanoparticle labelling probed by surface enhanced resonance Raman spectroscopy

Phil Douglas, Karen M. McCarney, Duncan Graham and W. Ewen Smith

Analyst, 2007, **132**, 865 - 867, DOI: 10.1039/b707660f

Submit your work today!

RSC Publishing

www.rsc.org/analyst

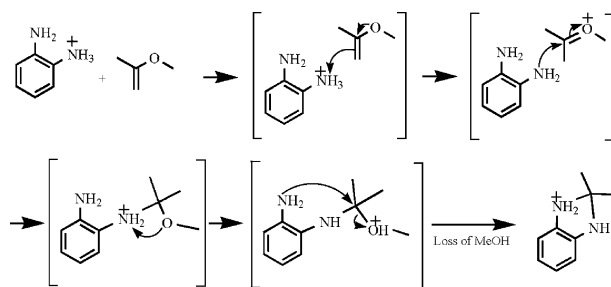
Registered Charity Number 207890

452

Regioselective ion–molecule reactions for the mass spectrometric differentiation of protonated isomeric aromatic diamines

Mingkun Fu, Penggao Duan, Sen Li, Steven C. Habicht, David S. Pinkston, Nelson R. Vinuesa and Hilka I. Kenttämäa*

Regioselective ion–molecule reactions allow the differentiation of protonated *ortho*-, *meta*- and *para*-isomers of phenylene- and toluenediamines in FT-ICR.



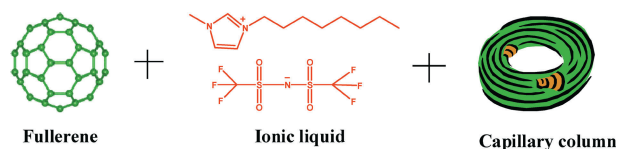
PAPERS

455

Fullerene-impregnated ionic liquid stationary phases for gas chromatography

Chieu D. Tran* and Santhosh Challa

Novel GC stationary phases based on amino and hydroxy derivatives of C₆₀ were successfully prepared using ionic liquids, and were able to separate polar as well as non-polar analytes.

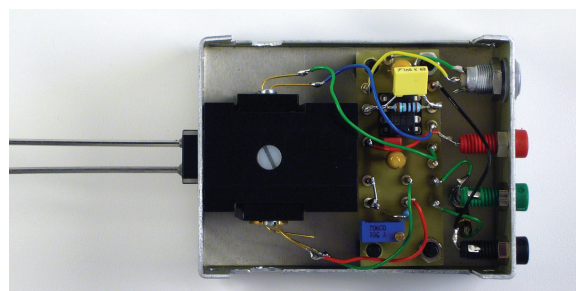


465

UV-absorbance detector for HPLC based on a light-emitting diode

Stefan Schmid, Mirek Macka and Peter C. Hauser*

Detection in the deep-UV at 255 nm has become possible using solid state optoelectronic components.



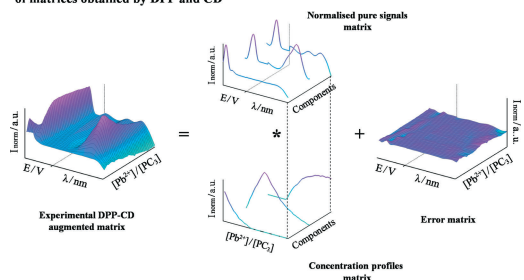
470

Combined use of the potential shift correction and the simultaneous treatment of spectroscopic and electrochemical data by multivariate curve resolution: analysis of a Pb(II)–phytochelatin system

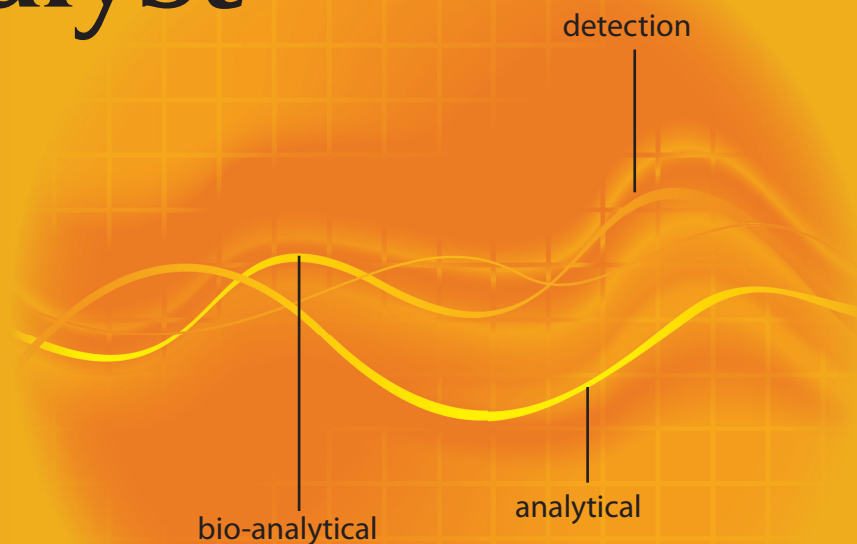
Aristides Alberich, José Manuel Díaz-Cruz,* Cristina Ariño and Miquel Esteban

A combination of differential pulse polarographic and circular dichroism measurements with (potential shift corrected) multivariate curve resolution by alternating least squares for data treatment is applied to the study of the binding of Pb(II) by the phytochelatin (γ -Glu-Cys)₃-Gly.

MCR-ALS analysis of the combination of matrices obtained by DPP and CD



The Analyst



Advanced instrumentation and methods

010850

Examples of recent articles include:

Diamond microelectrodes for in vitro electroanalytical measurements: current status and remaining challenges

Jinwoo Park, Veronika Quaiserová-Mocko, Bhavik Anil Patel, Martin Novotný, Aihua Liu, Xiaochun Bian, James J. Galligan and Greg M. Swain
Analyst, 2008, **133**, 17 - 24, DOI: 10.1039/b710236b

Photoelectrochemical ruler: measurement at the micron scale

Nicole Fietkau, Javier del Campo, Roser Mas, Francesc Xavier Muñoz and Richard G. Compton
Analyst, 2007, **132**, 983 - 985, DOI: 10.1039/b711828g

Rapid analysis of metabolites and drugs of abuse from urine samples by desorption electrospray ionization-mass spectrometry

Tiina J. Kauppila, Nari Talaty, Tiia Kuuranne, Tapio Kotiaho, Risto Kostiainen and R. Graham Cooks
Analyst, 2007, **132**, 868 - 875, DOI: 10.1039/b703524a

Forensic analysis of inks by imaging desorption electrospray ionization (DESI) mass spectrometry

D. R. Ifa, L. M. Gumaelius, L. S. Eberlin, N. E. Manicke and R. Graham Cooks
Analyst, 2007, **132**, 461 - 467, DOI: 10.1039/b700236j

Electrophoretic method for assessment of substrate promiscuity of a heterogeneous biocatalyst using an area imaging ultraviolet detector

Pawel L. Urban, Edmund T. Bergström, David M. Goodall, Sreedevi Narayanaswamy and Neil C. Bruce
Analyst, 2007, **132**, 979 - 982, DOI: 10.1039/b710495b

Submit your work today!

RSCPublishing

www.rsc.org/analyst

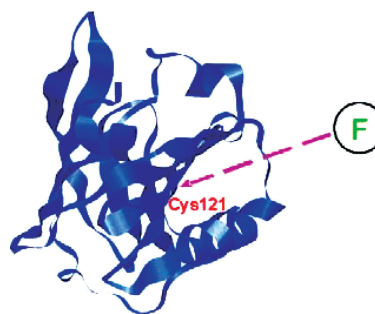
Registered Charity Number 207890

478

Characterization of local polarity and structure of Cys121 domain in β -lactoglobulin with a new thiol-specific fluorescent probe

Xiaochun Wang, Shujuan Wang and Huimin Ma*

A polarity-sensitive fluorescent probe, 3-(4-chloro-6-*p*-maleimidylphenoxy)-1,3,5-triazinylamino)-7-dimethylamino-2-methylphenazine, is developed to characterize the local polarity and structure of a protein, such as the Cys121 domain of β -lactoglobulin.



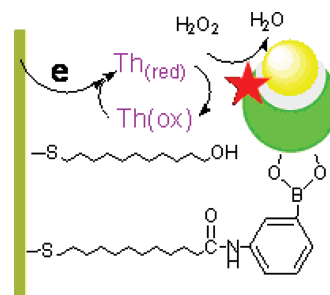
485



A reusable electrochemical immunosensor for carcinoembryonic antigen *via* molecular recognition of glycoprotein antibody by phenylboronic acid self-assembly layer on gold

Xiaoting Zhang, Yafeng Wu, Yifeng Tu* and Songqing Liu*

A reusable amperometric immunosensor for carcinoembryonic antigen detection based on the reversible boronic acid–sugar interactions is proposed.

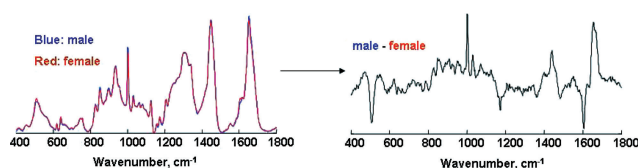


493

A novel method for human gender classification using Raman spectroscopy of fingernail clippings

Effendi Widjaja,* Geok Hong Lim and An An

A novel method for human gender classification by measuring the Raman spectrum of fingernail clippings is described. A combination algorithm of principal component analysis (PCA) and support vector machines (SVM) was used to perform the data classification, which provides classification accuracy up to 90%.

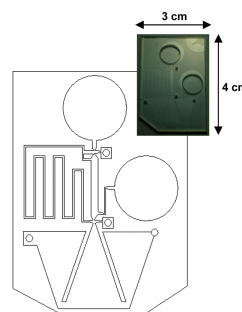


499

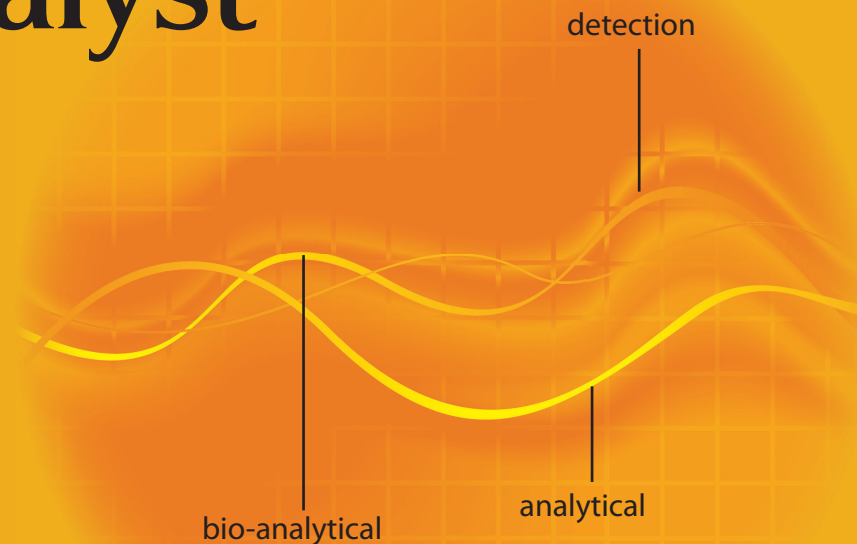
Fluorescence affinity sensing by using a self-contained fluid manoeuvring microfluidic chip

Jung Woo Hong, Kwang Hyo Chung and Hyun C. Yoon*

An application of a novel polymer microfluidic chip for sample exchange *via* natural capillary forces for immuno-analysis is described. The microfluidic device was designed to achieve sample replacement by capillary force only, which would be suitable for point-of-care-testing.



The Analyst



Analytical Nanoscience

010850

Examples of recent articles include:

Gas sensors based on nanostructured materials

Giselle Jiménez-Cadena, Jordi Riu and F. Xavier Rius

Analyst, 2007, **132**, 1083 - 1099, DOI: 10.1039/b704562j

Synthetic polymers for capture and detection of microorganisms

George Pasparakis and Cameron Alexander

Analyst, 2007, **132**, 1075 - 1082, DOI: 10.1039/b705097f

Recent progress in chemical detection with single-walled carbon nanotube networks

Pornnipa Vichchulada, Qinghui Zhang and Marcus D. Lay

Analyst, 2007, **132**, 719 - 723, DOI: 10.1039/b618824a

A solvent-based intelligence ink for oxygen

Andrew Mills and David Hazafy

Analyst, 2008, **133**, 213 - 218, DOI: 10.1039/b713450a

Nanofluidics and the role of nanocapillary array membranes in mass-limited chemical analysis

Enid N. Gatimu, Jonathan V. Sweedler and Paul W. Bohn,

Analyst, 2006, **131**, 705 - 709, DOI: 10.1039/b600158k

Ultrasensitive detection and molecular imaging with magnetic nanoparticles

Jian Yang, Jonathan Gunn, Shivang R. Dave, Miqin Zhang, Y. Andrew Wang and Xiaohu Gao

Analyst, 2008, **133**, 154 - 160, DOI: 10.1039/b700091j

Submit your work today!

RSC Publishing

www.rsc.org/analyst

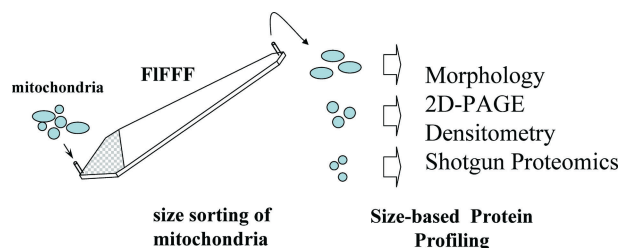
Registered Charity Number 207890

505

Separation of mitochondria by flow field-flow fractionation for proteomic analysis

Dukjin Kang, Sunok Oh, Pierluigi Reschiglian and Myeong Hee Moon*

Flow field-flow fractionation (FIFFF) is utilized for the size separation of rat liver mitochondria, and proteins of differently sized mitochondria are examined by shotgun proteomics and 2D-PAGE.

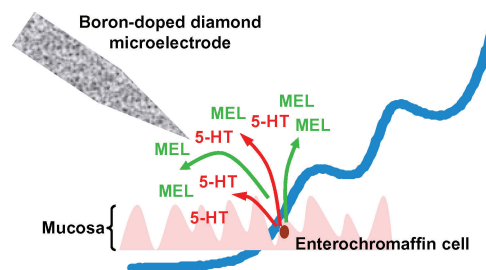


516

Continuous amperometric detection of co-released serotonin and melatonin from the mucosa in the ileum

Bhavik Anil Patel*

The detection of co-released neurotransmitters, serotonin and melatonin was conducted from enterochromaffin cells in the mucosal lining of the ileum using a boron-doped diamond microelectrode.

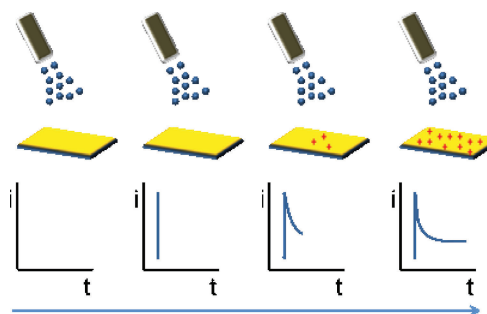


525

Surface effects and electrochemical cell capacitance in desorption electrospray ionization

Michael Volný, Andre Venter, Scott A. Smith, Marco Pazzi and R. Graham Cooks*

Experiments demonstrate that the DESI source behaves as a dc capacitor. The charging and discharging behaviour was observed using different surfaces by making current measurements on a plate at the entrance to the mass spectrometer, as well as by measuring ion current in the linear ion trap within the vacuum system of the mass spectrometer.

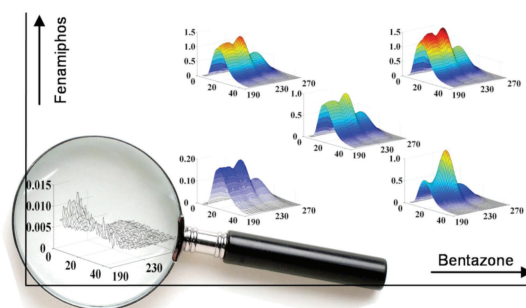


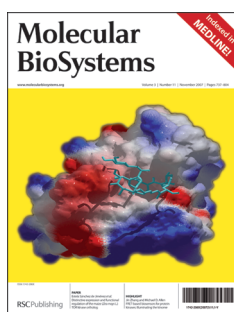
532

Detection limit estimator for multivariate calibration by an extension of the IUPAC recommendations for univariate methods

Miren Ostra, Carlos Ubide,* Maider Vidal and Juan Zuriarrain

A method to estimate the limit of detection when multivariate calibration is used. The main feature is that it uses raw multivariate data instead of a univariate surrogate signal.





www.molecularbiosystems.org

It's official, *Molecular BioSystems* has separated from host journal, *Chemical Communications*, and is now a fully fledged solo publication. Its availability since launch to readers of *Chemical Communications* and the online hosts, *Organic & Biomolecular Chemistry*, *Lab on a Chip*, *The Analyst* and *Analytical Abstracts*, has ensured that *Molecular BioSystems* received a large and interdisciplinary audience from the outset. *Analyst* readers wishing to continue to read *Molecular BioSystems* now need to recommend the journal to their librarian. Fill in the online recommendation form at www.rsc.org/libraryrecommendation

AUTHOR INDEX

- | | | | |
|---------------------------------|-------------------------|-----------------------------|-------------------------|
| Alberich, Aristides, 470 | Hong, Jung Woo, 499 | Patel, Bhavik Anil, 516 | Venter, Andre, 525 |
| An, An, 493 | Ji, Hai-Feng, 434 | Pazzi, Marco, 525 | Vidal, Maider, 532 |
| Ariño, Cristina, 470 | Jiang, Xuan, 417 | Pereiro, R., 444 | Vinueza, Nelson R., 452 |
| Buchapudi, Koutilya R., 434 | John, Thong T. L., 448 | Pinkston, David S., 452 | Volný, Michael, 525 |
| Challa, Santhosh, 455 | Kang, Dukjin, 505 | Reschiglian, Pierluigi, 505 | Wang, Shujuan, 478 |
| Chung, Kwang Hyo, 499 | Kenttämä, Hilka I., 452 | Riddle, Justin A., 417 | Wang, Xiaochun, 478 |
| Cooks, R. Graham, 525 | Lee, Dongwhan, 417 | Rubakhin, Stanislav S., 423 | Widjaja, Effendi, 493 |
| Costa-Fernández, J. M., 444 | Li, Sen, 452 | Sanz-Medel, A., 444 | Wu, Yafeng, 485 |
| Díaz-Cruz, José Manuel, 470 | Lim, Geok Hong, 493 | Schmid, Stefan, 465 | Xu, Xiaohe, 434 |
| Duan, Penggao, 452 | Liu, Songqing, 485 | Schulte, Marvin K., 434 | Yang, Xin, 434 |
| Esteban, Miquel, 470 | Loh, Kian Ping, 448 | Smith, Scott A., 525 | Ye, Xiaoying, 423 |
| Fernández-Argüelles, M. T., 444 | Ma, Huimin, 478 | Sweedler, Jonathan V., 423 | Yoon, Hyun C., 499 |
| Fu, Mingkun, 452 | Macka, Mirek, 465 | Tan, Chow Khim, 448 | Zhang, Xiaoting, 485 |
| Gao, Hongyan, 434 | Moon, Myeong Hee, 505 | Tran, Chieu D., 455 | Zuriarrain, Juan, 532 |
| Habicht, Steven C., 452 | Oh, Sunok, 505 | Tu, Yifeng, 485 | |
| Hauser, Peter C., 465 | Ostra, Miren, 532 | Ubide, Carlos, 532 | |

FREE E-MAIL ALERTS AND RSS FEEDS

Contents lists in advance of publication are available on the web *via* www.rsc.org/analyst – or take advantage of our free e-mail alerting service (www.rsc.org/ej.alert) to receive notification each time a new list becomes available.



Try our RSS feeds for up-to-the-minute news of the latest research. By setting up RSS feeds, preferably using feed reader software, you can be alerted to the latest Advance Articles published on the RSC web site. Visit www.rsc.org/publishing/technology/rss.asp for details.

ADVANCE ARTICLES AND ELECTRONIC JOURNAL

Free site-wide access to Advance Articles and the electronic form of this journal is provided with a full-rate institutional subscription. See www.rsc.org/ejs for more information.

* Indicates the author for correspondence: see article for details.



Electronic supplementary information (ESI) is available *via* the online article (see <http://www.rsc.org/esi> for general information about ESI).

Chemical Technology

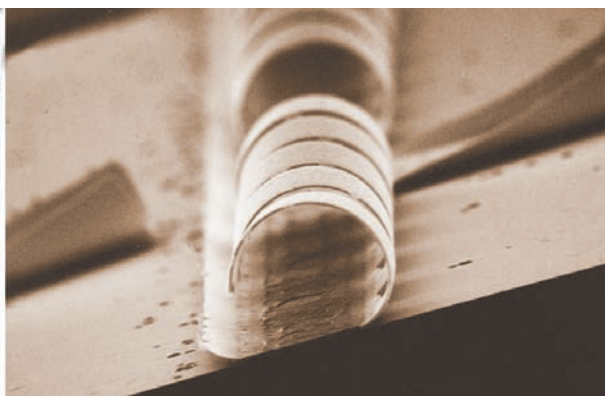
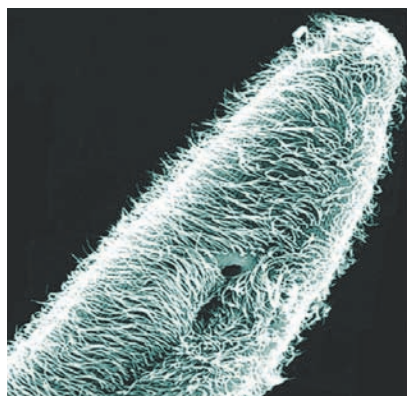
Layered polyimide and chromium curl and uncurl by applying a voltage

Miniature mixing inspired by nature

Dutch scientists have copied nature to develop a faster and more efficient method for mixing small volumes of liquid. They were inspired by microorganisms that use tiny oscillating hairs (called cilia) to move through liquid, and made artificial cilia to use in microfluidics.

Microfluidics is the study of fluid flow in structures with dimensions smaller than a millimetre, with devices as small as a credit card. Key applications for these devices include biochips, especially the immediate point-of-care diagnosis of diseases. The problem with such a small device is that good mixing is almost impossible. Usually, mixing is done by etching grooves into the fluid channels or applying an electrical pulse or sound wave. However, there is no real control over the mixing in these cases, according to Jaap den Toonder of the Philips Research Laboratory in Eindhoven.

Toonder and colleagues have therefore made artificial cilia from a double layer of thin polymer, called polyimide, and a thin conductive



layer of chromium. The artificial cilia looks a lot like a curled-up leaf.

These tiny mixers are activated by applying a voltage. When applied, the rolled-up cilia uncurl. When the voltage is turned off, the cilia roll back up by elastic recovery. In this way, the mixing can be turned on or off by demand and in any location in the device, an advantage over other mixing methods.

Andreas Manz, head of the Institute for Analytical Sciences in Dortmund, Germany, commented

Artificial cilia (right) mimic real cilia such as those on a Paramecium micro-organism (left)

that the use of the artificial cilia for mixing was intriguing, as 'in biological systems cilia are used for transport'.

When questioned about the future, den Toonder said the next steps were to find alternative ways to activate the artificial cilia, such as magnetically-driven systems. The team's final goal is to develop artificial cilia 'into a versatile lab-on-a-chip devices'.
Rebecca Brodie

Reference
J den Toonder *et al*, *Lab Chip*, 2008, DOI: 10.1039/b717681c

In this issue

Detecting a microbe among millions

Piezoelectric cantilever picks out anthrax in real time

Metals without the meltdown

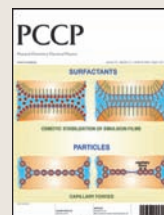
An environmentally friendly alternative to pyrometallurgical processes

Instant insight: Organic field-effect transistors

Marta Mas-Torrent and Concepció Rovira look at how small molecules could be used as processable semiconductors

Interview: Flying high with nanomedicine

Jinwoo Cheon explains how nanoparticles can be used in medical diagnostics



The latest applications and technological aspects of research across the chemical sciences

Application highlights

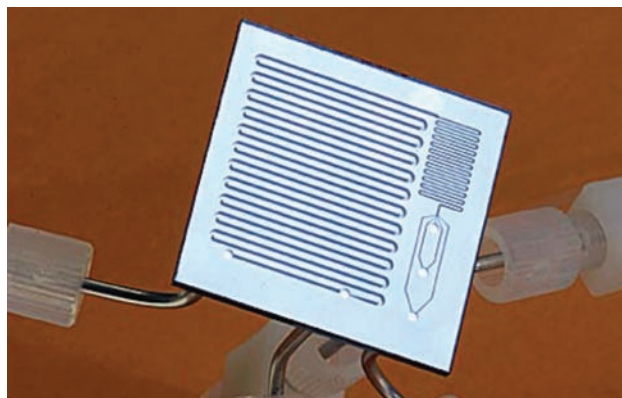
Amides in minutes using continuous flow microreactor

Big impact for small reactors

Micoreactors can be a powerful tool for product synthesis in the pharmaceutical industry, say Swiss and Swedish scientists. Their application of microreactor technology to an amide bond formation reaction illustrates this.

Peter Seeberger from the Swiss Federal Institute of Technology, Zurich, and colleagues showed that their method can cope with a range of substrates, and applied it to the synthesis of two pharmaceutically active compounds. They claim that the microreactor-based technique is faster and safer than traditional methods, and that scale-up to bulk synthesis level is not a problem.

‘One can think of a microreactor as a small pipe,’ explained Seeberger. ‘Chemicals are pumped through the pipe and additional inlets can be used to add reagents.’ Microreactors allow fast mixing, quick and even heating, and the generation of high pressures. Together this



makes for short reaction times; Seeberger’s amide bond formation was completed within two minutes, compared to four to sixteen hours using conventional methods. In addition, microreactor systems are safer because the small reaction volumes mean that any hazardous intermediates are formed only in small amounts.

Safe, efficient and versatile: microreactors could become the method of choice for industry

Reference

T Gustafsson *et al.*, *Chem. Commun.*, 2008, 1100 (DOI: 10.1039/b719603b)

Steve Haswell, an expert in microreactor chemistry from the University of Hull, UK, said that microreactor technology has great potential for industry. Possible applications are reaction optimisation, library building, and safe and efficient product production, he said. The type of work performed by Seeberger ‘should make medicinal chemists sit up and look seriously at the contribution microreactor technology has to offer,’ said Haswell.

To illustrate the technique’s versatility, Seeberger’s group is working on applying microreactors for fluorinations and in radical and photochemistry. The group also has close collaborations with industry to look at real-life problems that microreactors could be used to solve. ‘Industry is getting into this technology big-time,’ said Seeberger.

Danièle Gibney

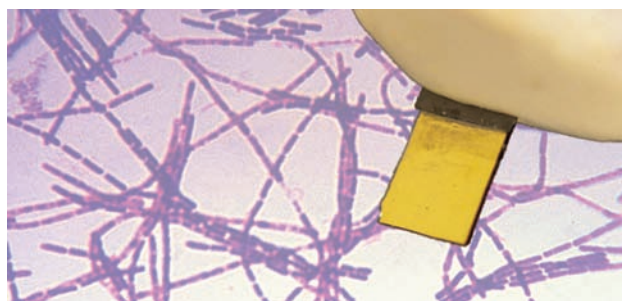
Piezoelectric cantilever picks out anthrax in real time

Detecting a microbe among millions

A sensor that can discriminate between closely related bacteria has been developed by materials scientists in the US.

Wan Shih and colleagues at Drexel University in Philadelphia immobilised a rabbit antibody to *Bacillus anthracis* (anthrax) on a piezoelectromicrocantilever sensor (PEMS). They then exposed the sensor to suspensions of anthrax spores and some of its close relatives. Because the chemical structures in the spore coats of these bacteria are similar, they all bind to the anthrax antibody to some extent. However, the binding interactions of the ‘close relatives’ are weaker than that of anthrax itself.

PEMS uses antibodies, which have high affinity and specificity for different microbes, attached to tiny cantilevers. ‘These can be thought of as tiny diving boards made from piezoelectric material that can detect small particles, like



deadly *Bacillus anthracis* spores, by vibrating,’ explained Wei-Heng Shih, a member of the US team. The cantilevers’ combination of specific antibody and sensitivity enables the sensor to accurately detect any micro-organism (depending on the antibody used) in real time, with no added chemicals, radioactive tags or external manipulation. ‘The sensor can detect its preferred microbe in the presence of a million of its closely related cousins. It can detect a needle in a haystack!’ said Wei-

The PEMS cantilever vibrates when anthrax spores bind to an attached antibody

Reference

J-P McGovern *et al.*, *Analyst*, 2008, DOI:10.1039/b715948j

Heng Shih.

To test if the PEMS could preferentially detect anthrax spores, the team flowed suspensions of the different bacteria across the sensor. The team observed that, at first, increasing the flow speed of the bacterial suspensions across the sensor led to increased binding of all four species because the sensor surface was exposed to more spores. But at higher flow rates, preferential anthrax-antibody binding was increased and binding to close relatives was suppressed.

‘This result means that flow can be used to enhance the specificity of antibody-based detection,’ said Wan Shih. ‘With the right antibodies or receptors our sensor can detect air or food-borne pathogens and blood or urinary biomarkers for human diseases like cancer or AIDS...and it will make detection possible in minutes instead of days,’ she added.

Janet Crombie

X-ray fluorescence reveals metals diffusing from paint into glass

Watching paint die

A new analytical technique from German scientists may help restore decaying glass paintings.

Birgit Kanngiesser led researchers from Berlin's Federal Institute for Materials Research and Testing, and the Technical University of Berlin, in studying reverse glass paintings – made by painting onto the back of a glass sheet. Unlike stained glass, these paintings are not fired and the contact between glass and paint is fragile.

The team used a technique called 3D micro x-ray fluorescence (3D micro XRF) to identify the elements in the corroded areas of the glass of a 19th century painting and compare them to healthy areas, without further damaging the artwork.

As with any XRF technique, micro XRF involves firing an x-ray beam at the sample to eject electrons. Higher-



orbital electrons fall down to fill the gaps left by removed electrons, and in doing so emit photons of radiation characteristic to a particular element. In micro XRF, though, the beam can be focused onto a very small area. By using a powerful x-ray source and applying their recently-discovered calibration improvements to the

Reverse glass paintings: beautiful but fragile

Reference

B Kanngiesser *et al.*, *J. Anal. At. Spectrom.*, 2008, DOI: 10.1039/b717286a

technique, the researchers were able to study the composition of layers buried under the surface.

Kanngiesser's team identified the paints used and found that lead and mercury had diffused into the glass. The information should help conservators find the best way to protect and restore reverse glass artworks.

Kanngiesser hopes the non-destructive technique will extend to other fields, such as environmental science or archaeometry. 'Unlike other elemental imaging methods, there is no principal size restriction of the objects investigated,' she explains. 'And for life sciences the possibility of obtaining elemental distribution in virtual cross sections without having to cut the sample might open up new ways of in vivo measurements.' *Clare Boothby*

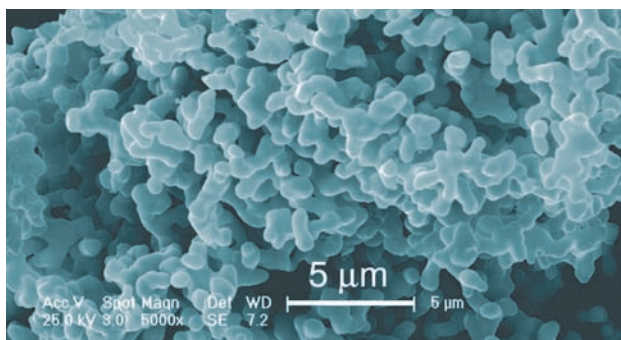
An environmentally friendly alternative to pyrometallurgical processes

Metals without the meltdown

Scientists have found a practical, cheap and environmentally friendly way of producing the industrially important metal niobium.

Niobium is used in a variety of applications, from superalloys to optics. Total world production is nearly 23 000 tonnes per year. But like many industrially important metals, it is extracted from metal ores and minerals using high temperatures – a relatively costly process. 'Alternative processes are essential to provide environmentally acceptable and energy efficient routes to metal extraction,' explains Frank Walsh, an expert on industrial electrochemistry from the University of Southampton, UK. 'In particular, minimising the number of steps in a production route and achieving direct transformation of minerals to metals is a critical subject area.'

George Zheng Chen from the University of Nottingham, UK, and colleagues at Wuhan University, China, have now cut the energy



consumption of niobium extraction by a third, by improving on the already green FFC Cambridge process, named for its inventors Fray, Farthing and Chen, and originating in the late 1990s. In the FFC process, which is carbon-emission free, metals and alloys are extracted directly from their solid oxides using electrolysis in molten calcium chloride.

Chen and co-workers found that electrolysis of niobium oxide in a three-electrode cell using a variable voltage uses significantly less energy

Niobium oxide pellets after electrolysis in calcium chloride

Reference

T Wu *et al.*, *Phys. Chem. Chem. Phys.*, 2008, **10**, 1809 (DOI: 10.1039/b719369f)

than the FFC's constant voltage two-electrode system. However, the set-up is more complicated and so impractical in large scale operations. To get around this problem the scientists mimicked variable voltage with computer-aided control (CAC) of the two-electrode cell. Modifying the FFC process in this way results in a 'more than 37 per cent saving in energy consumption,' the team says. Chen says the energy-saving modification shouldn't require any changes to the FFC cells.

'CAC is demonstrated in principle for niobium extraction, but it is perfectly suitable for other reactive metals such as tantalum, titanium, zirconium and many rare earths,' says Chen. Also, adds Walsh, 'the system described provides an attractive and direct route to the formation of speciality alloys.'

The FFC Cambridge Process is being commercialised by a spin-out company – Metalysis, which has formed strategic partnerships with industry, including BHP Billiton and Rolls-Royce. *Freya Mearns*

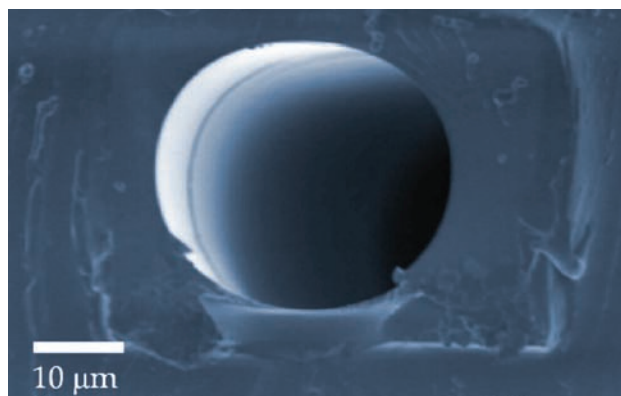
Coating improves chemical resistance of channels in microfluidic devices

Glass-coated microchannels

Scientists in the US have developed a simple method of coating the channels of microfluidic devices to make them more resistant to chemicals. David Weitz and colleagues from Harvard University, Cambridge, used a sol-gel method to create a glass coating on polydimethylsiloxane (PDMS) microchannels.

PDMS, a type of silicone rubber, is easy to make into microfluidic devices using soft lithography, where the material is 'stamped' with a channel pattern. This makes it ideal for large-scale use. However, PDMS is permeable to liquids and gases, which can affect reactions occurring in the channels. Additionally, organic solvents make the PDMS channels swell, degrading device performance. Glass is far more chemically robust but is much more difficult to make into microfluidic devices.

The glass coating developed by Weitz's group is easily deposited on PDMS channels and acts as a barrier,



providing resistance to chemicals and solvents. Weitz said that this coating method would make device production easier as it 'combines the chemical robustness of glass with the ease of fabrication of PDMS.'

To form the coating, Weitz's group used a sol-gel mixture that begins as a fluid and hardens into a glass. They filled the channels with the mixture, initiated a gelation reaction and

The best of both worlds: glass-coatings for PDMS channels mean robustness and easy device fabrication

Reference
A R Abate *et al*, *Lab Chip*, 2008, DOI: 10.1039/b800001h

then used air to flush out most of the material, leaving the glass coating.

The scientists discovered that the coated channels were resistant to the fluorescent chemical Rhodamine B. After an hour of exposure to the organic solvent toluene the channels changed very little. By contrast, uncoated channels swelled upon exposure to toluene.

Stephen Haswell, who develops microfluidic devices at the University of Hull, UK, said that although there would be issues with performing reactions at high temperatures, the work represented a step towards merging the advantages of PDMS and glass. 'Lack of chemical resistance is a big problem, and it will be something of a breakthrough to extend the fabrication benefits of PDMS to give more glass-type robustness,' he said.

Weitz's group is working on refining the technique so that the thickness of the coating can be more finely controlled.

Fay Riordan

Tuneable system picks out particles of the required size

To sort, simply stretch

Researchers in Sweden have come up with a straightforward method for sorting particles in microfluidics – simply stretching the microchannel.

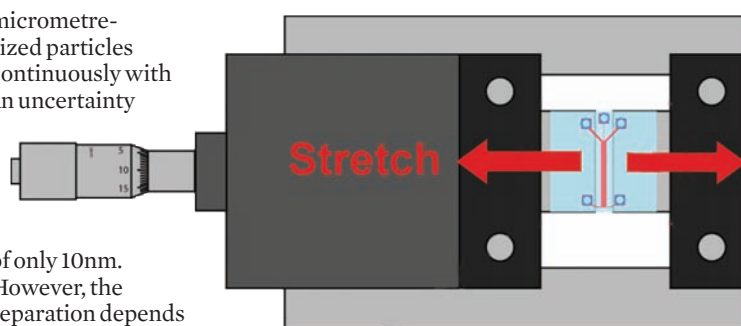
Sorting particles by size, anything from cells to plastic beads, is very useful in both analytical and preparative chemistry, but it is not always easy to achieve. In particular, a tuneable system, so that particles of different sizes can be sorted by the same device, is a major challenge. Jason Beech and Jonas Tegenfeldt of Lund University have struck upon a solution that makes use of the fact that the material used to make many microfluidic devices is very elastic.

Several methods have been proposed to sort particles in microfluidic devices, and one of the most promising is 'deterministic lateral displacement'. Originally reported by Huang and co-workers,¹ the technique is able to separate

micrometre-sized particles continuously with an uncertainty

of only 10nm. However, the separation depends on distances between obstacles in a narrow channel and so the channel has to be designed to separate only the particle of desired size. Beech and Tegenfeldt realised that simply stretching the microchip changes the separation parameters. This gives a tuneable sorting device.

'The concept of macroscopic stretching to change the dimensions of fluidics devices on the nanometre to micrometre scale is something



Stretching a microchip changes its separation parameters giving a tuneable sorting system

References
J P Beech and J O Tegenfeldt, *Lab Chip*, 2008, DOI: 10.039/b719449h
1 L R Huang *et al*, *Science*, 2004, **304**, 987

that has not been exploited fully in the microfluidics community and could, with a little imagination, lead to promising applications,' explained Beech 'Having had the idea that stretching the devices would tune them, we began to realise the wealth of

interesting applications that this could lead to.'

Beech hopes the idea will spread. 'It will be interesting to see if others put the concept of stretching fluidics devices to use,' he said, 'but the challenges are those of engineering and materials science, namely making more stretchable, more robust and more homogenous devices.' *Edward Morgan*

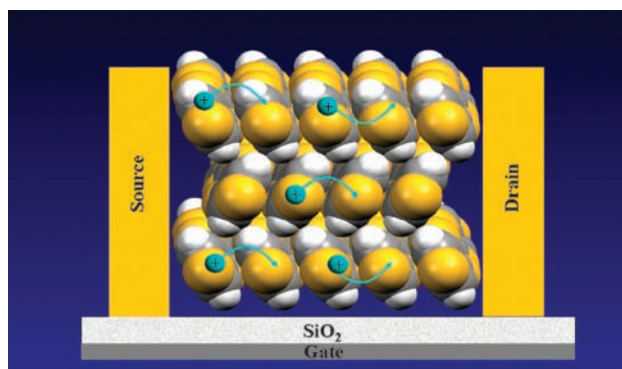
Organic field-effect transistors

Marta Mas-Torrent and Concepció Rovira of the Institute of Science of Materials (CSIC) in Barcelona, Spain, look at how small molecules can be used as processable semiconductors

Our daily life involves the continuous use of field-effect transistors: they are the main logic units, functioning as either switches or amplifiers, controlling current flow in electronic circuits. A field-effect transistor is a three-terminal device in which current flows through a semiconductor from the 'source' terminal to the 'drain'. This flow is controlled at the third 'gate' terminal by a voltage that creates an electric field through the insulator (dielectric) on which the semiconductor is deposited. Since the invention of the first transistor in 1947 by John Bardeen, William Shockley and Walter Brattain, the vast majority of electronic devices have been based on inorganic semiconductors and, in particular, on silicon.

Over the past few years, however, organic field-effect transistors (OFETs) have attracted a great deal of interest due to their unique processing characteristics. Organic materials offer the benefit that they can be printed over large areas on plastic, flexible substrates at low temperature by solution-based techniques, which would result in a dramatic reduction of manufacturing costs. Though the first OFETs did not transport charge as well as inorganic materials, the best ones nowadays are achieving charge carrier mobilities of the same order as amorphous silicon. Organic-based electronics will not replace high density and high speed silicon circuits, but might play an important role in applications such as identification tags, electronic bar codes or active matrix elements for displays.

OFETs have been mainly based on two types of semiconductors that feature π - π interactions: conjugated polymers and small conjugated



molecules. Polymers are deposited from solution, allowing for low cost electronics. However, the higher molecular disorder in polymers limits their charge transport, typically resulting in lower mobilities compared to devices based on small molecules. On the other hand, devices prepared with small conjugated molecules have to be prepared more expensively by evaporating organic materials, due to their low solubility in common organic solvents. Therefore, to promote the development and use of organic semiconductors, there is a clear need to find materials that can be processed in solution and that simultaneously achieve a high OFET mobility.

One way of imparting solubility to organic semiconductors is to prepare a precursor compound that can be converted into the parent semiconductor by heat or irradiation. An alternative strategy is to structurally modify organic semiconductors to impart solubility and, if possible, also achieve higher stability and increase π - π interactions. Semiconductors such as acenes and oligothiophenes (classified as p-type, since the charge carriers are mainly holes) have been processed by techniques such as spin coating and drop or zone

casting, and very high performances have been achieved.

Currently, there is a growing interest in developing n-type semiconductors (where charge carriers are electrons) and ambipolar devices (which conduct both electrons and holes) in order to fabricate complementary circuits. The development in these devices is still far from the performance achieved with p-type materials, because transport in n-channel conductors is easily degraded by air and finding suitable metals for contacts is difficult.

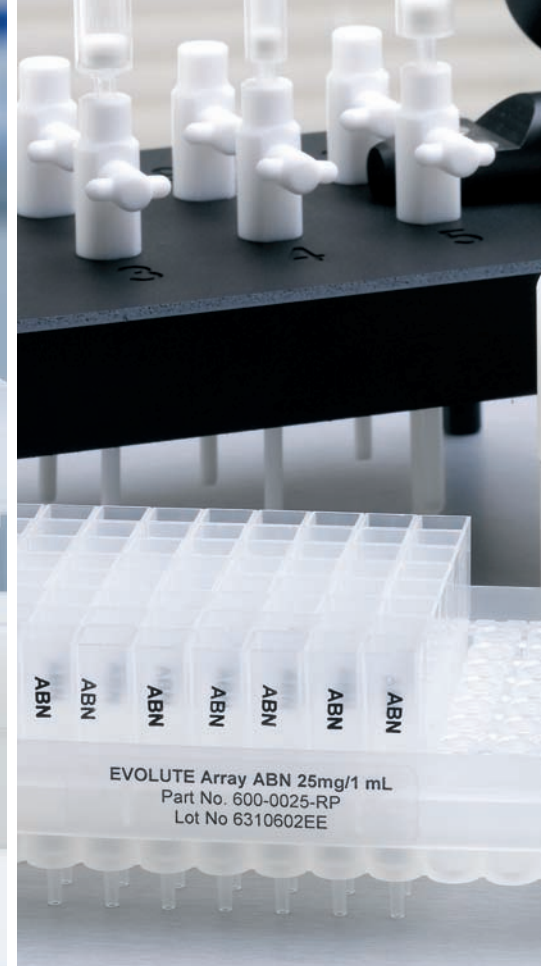
Circuits based on organic transistors are being extensively investigated for a range of applications. One of the first emerging devices realised with OFETs is flexible electronic paper (see *Chemistry World*, April 2007, p15), where organic transistors switch pixels formed by charged pigments. OFETs also offer great promise for applications in chemical and biological sensing: organic semiconductors can interact with different analytes and it is possible to transduce the chemical information to electronic information, creating an 'electronic nose'. And the electrical switching of an OFET has been combined with an organic semiconductor's ability to generate light, to create organic light-emitting transistors (OLETs).

OFETs promise to be important in applications ranging from sophisticated medical diagnostics to 'smart' clothes that can display changing images. New markets will undoubtedly appear in areas where electronics meets with information technology, biomedicine or optics.

Read *Concepció Rovira and Marta Mas-Torrent's critical review in issue 4, 2008, of Chemical Society Reviews.*

Reference

M Mas-Torrent and C Rovira, *Chem. Soc. Rev.*, 2008, **37**, 827 (DOI: 10.1039/b614393h)



IST Sample Preparation • Bioanalysis • Clinical • Environmental • Forensic • Agrochemical • Food • Doping Control

EVOLUTE® CX **NEW!**

Mixed-mode selectivity, generic methodology and efficient extraction

EVOLUTE® CX mixed-mode resin-based SPE sorbent extracts a wide range of **basic drugs** from biological fluid samples. EVOLUTE CX removes matrix components such as proteins, salts, non-ionizable interferences and phospholipids, delivering cleaner extracts with reproducible recoveries for accurate quantitation.

EVOLUTE® ABN

Minimize matrix effects, reduce ion suppression and concentrate analytes of interest

EVOLUTE® ABN (Acid, Base, Neutral) is a water-wettable polymeric sorbent optimized for fast generic reversed phase SPE. Available in 30 μm columns and 96-well plates for bioanalysis and **NEW 50 μm columns** – ideally suited for environmental, food/agrochemical and industrial analysis as well as forensic and doping control applications.

Come by **Booth #1611 at ACS** or contact your local Biotage representative to request a **FREE** sample.

Flying high with nanomedicine

Jinwoo Cheon tells Stephen Davey how nanoparticles can be used in medical diagnostics



Jinwoo Cheon

Jinwoo Cheon is professor of chemistry at Yonsei University, Korea, and head of the nanomaterials division of the Nano-Medical National Core Research Center of Korea. His research areas include the fabrication and shape control of inorganic nanocrystals, nanoscale biomagnetics, and the applications of nanocrystals for biomedical sciences. Jinwoo is on the editorial board of *Journal of Materials Chemistry*.

What inspired you to become a scientist?

I have always loved the arts, and art is what I saw in my first chemistry classes. The representation of molecules and the systematic formation or cleavage of bonds to give different molecules with different properties fascinated me. I found it easy to comprehend what was happening in this molecular world and I viewed it as if playing a game of Lego.

Can you tell me a little about your background?

My training is in the area of synthetic inorganic chemistry. I studied organometallic and materials chemistry under the guidance of some wonderful mentors including Gregory Girolami at the University of Illinois, John Arnold at Berkeley, and Jeffrey Zink at UCLA. The areas of molecular precursor chemistry for materials synthesis and their transformations from a mechanistic point of view are of particular interest. I have extended these concepts to nanoparticle synthesis in which the size, shape, and composition are of significant importance to their material properties. I hope to make major contributions towards solving today's health issues, such as cancer, and energy storage concerns by using nanoscale materials.

One of the applications of your research into magnetic nanomaterials is in medical diagnostics. Can you explain how this works?

Nanoparticles are important in biomedical applications due to their small size and wonderful properties. Magnetic nanoparticles are especially useful for biological separation, diagnostics and treatment of diseases. By tuning their magnetism by varying their size or composition, we have been able to fabricate extremely sensitive magnetic resonance imaging (MRI) probes. They selectively target biological species with strong enhancement of detection sensitivity for the diagnosis of smaller cancers. We are also developing biocompatible nanoparticles which are free of potential toxicity without losing their materials properties.

What's the trickiest problem that you've faced, and how did you solve it?

Interdisciplinary research topics such as nanomedicine require collaboration between different research fields. This is not always easy as it is difficult to get people to buy into concepts that they are not familiar with.

I often have to be persistent and an advocate for our nanomaterials. However, synergistic results between research groups are the most important outcome. As scientists, researchers and educators, we should try to understand each other's language and to overcome the boundaries between different disciplines.

As chemists, we are in a good position to be translators of these different languages since chemistry plays a pivotal role in interfacial problem solving and bridges interdisciplinary subjects.

What is the secret to running a successful research group?

Highly motivated and enthusiastic students are the most important assets. A research group's goals cannot be realised without open communication and ownership. Members must share the group's vision but also be willing to take a chance with new ideas and bring their own insight to the table. There has to be an atmosphere of trust and mutual respect in order to nurture the growth of all involved.

What is the most rewarding aspect of your work?

Working with next generation chemists who will be the leaders in our global community through our research efforts is the most rewarding part. Hopefully, in the future, new nanomaterials that are developed as a result of our work can contribute towards enhancing the quality of human life in terms of medical sciences or energy-related technologies.

Do you have a message for young scientists?

Try to develop your own interpretation of science. In your pursuit of becoming a scientist, be persistent and enjoy the ride and you will be rewarded in the future, regardless of where the road takes you.

Which scientist, current or historic, do you most admire and why?

Marie Curie. She was not only a great chemist but she was successful despite being in adverse surroundings, which included gender and racial discrimination and extremely poor research environments.

If you weren't a scientist, what would you be?

A pilot, if wearing glasses did not matter!

Essential elements

A winning combination!

Visit the RSC stand, booth 411, at the ACS Spring National Meeting & Exposition in New Orleans, US, 6–10th April 2008 and you could be a winner! To celebrate the success of their monthly podcast and the launch of their new mini-podcast 'Chemistry in its element – a tour of the periodic table' the award-winning *Chemistry World* is offering an iPod to one lucky listener.

Or give your energy levels a boost with our cookies and cakes event in anticipation of the summer launch of our brand new journal - *Energy & Environmental Science*, linking all aspects of the chemical sciences relating to energy conversion and storage, alternative fuel technologies and environmental science. Sign up to e-alerts to secure your entry into a prize draw for a solar-powered charger for your mobile phone, MP3 player and other mobile devices.

Meet the editors of our



journals, pick up some free copies and make the most of the RSC books sale – offering up to

20% off selected titles

Celebrate with us as four titles from our successful journal portfolio mark their 10th year of publication. *CrystEngComm*, *Green Chemistry*, *Journal of Environmental Monitoring* (*JEM*), and *Physical Chemistry Chemical Physics* (*PCCP*) have all made huge advances in their first decade. Check out the *RSC eBook Collection*, a fully searchable online reference library covering more than 750 titles, or discuss with us the award-winning *RSC Prospect* enhanced HTML articles.

Plus, why not take this opportunity join over 44 000 people worldwide by becoming a member of the RSC and benefit from the wealth of knowledge that we contribute to the chemical science community.

We look forward to seeing you there!

Visit www.rsc.org/rscatacs

Hot off the press



The μTAS 2008 conference in San Diego, US, is featuring a new award sponsored by *Lab on a Chip* titled 'Under the Looking Glass: Art from the World of Small Science.' Applications are encouraged from any person attending the conference and the winner will be selected by a panel of senior scientists in the field of μTAS.

Applications must show a photograph, micrograph or other accurate representation of a system that would be of interest to the μTAS community. They must also contain a brief caption that describes the illustration's content and its scientific merit. The winner will be selected on the basis of aesthetic appeal, artistic allure and scientific merit. In addition to having the image featured on the cover of *Lab on a Chip*, the winner will also receive a financial award at the conference.

For more information email loc@rsc.org

April free access

Do you have online access to one or more journals from RSC Publishing? Would you like to have access to even more content?

From April 1st to April 30th 2008, you can!

Like any organisation, we are keen to reward our loyal customers. So, to show our appreciation for your continued support of RSC journals, we are providing you with free

online access to all of our online journals – completely free!

All you need is a current institutional subscription (or rights to access online) for one or more RSC journal titles. Then, for the whole of April 2008, you and your colleagues will be able to read all content, published between 1997 and the present day, in all RSC journals.

A complete list of all journals

included in this offer is listed on the website. The list includes all our established titles, such as *ChemComm*, *The Analyst*, *Green Chemistry*, *Lab on a Chip* and *Journal of Materials Chemistry*, as well as some more recent additions *Soft Matter* and *Molecular BioSystems*.

Visit www.rsc.org/april_access for full details

Chemical Technology (ISSN: 1744-1560) is published monthly by the Royal Society of Chemistry, Thomas Graham House, Science Park, Milton Road, Cambridge UK CB4 0WF. It is distributed free with *Chemical Communications*, *Journal of Materials Chemistry*, *The Analyst*, *Lab on a Chip*, *Journal of Atomic Absorption Spectrometry*, *Green Chemistry*, *CrystEngComm*, *Physical Chemistry Chemical Physics* and *Analytical Abstracts*.

Chemical Technology can also be purchased separately. 2008 annual subscription rate: £199; US \$396. All orders accompanied by payment should be sent to Sales and Customer Services, RSC (address above). Tel +44 (0)1223 432360, Fax +44 (0)1223 426017 Email: sales@rsc.org

Editor: Neil Withers

Associate editors: Nina Notman, Celia Clarke

Interviews editor: Joanne Thomson

Web editors: Michael Spencelayh, Debora Giovanelli

Essential Elements: Daniel Bradnam, Valerie Simpson and Kathryn Lees

Publishing assistant: Ruth Bircham

Publisher: Graham McCann

Apart from fair dealing for the purposes of research or private study for non-commercial purposes, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988 and the copyright and Related Rights Regulations 2003, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission of the Publisher or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency in the UK. US copyright law is applicable to users in the USA.

The Royal Society of Chemistry takes reasonable care in the preparation of this publication but does not accept liability for the consequences of any errors or omissions.

Royal Society of Chemistry: Registered Charity No. 207890.

RSC Publishing