ACTION TD1105 EuNetAir

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

BOOKLET

SECOND INTERNATIONAL WORKSHOP
New Sensing Technologies for Indoor and Outdoor Air Quality Control

Palazzo Nervegna-Granafei (City Mayor Headquarters)

Brindisi (Italy), 25 - 26 March 2014

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

ENTE PER LE NUOVE TECNOLOGIE, L'ENERGIA E L'AMBIENTE

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ESSEM Domain

COST Action TD1105

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability - EuNetAir

SECOND INTERNATIONAL WORKSHOP on New Sensing Technologies for Indoor and Outdoor Air Quality Control

Brindisi (Italy), 25 - 26 March 2014

Palazzo Nervegna-Granafei (City Mayor Headquarters)
Via Duomo, 20 - 72100 Brindisi, Italy

organized by **ENEA - Brindisi Research Center**	
supported by **Brindisi Municipality**	

AGENDA	
25 March 2014 - Tuesday	
08:30 - 18:00	***REGISTRATION***
09:00 - 09:30	**Welcome Address**
09:30 - 11:00	**Session 1: Plenary Session**
11:00 - 11:30	*Coffee Break*
11:30 - 13:00	**Session 2: Oral Presentation**
13:00 - 14:30	*Lunch*
14:30 - 16:00	**Session 3: Oral Presentation**
16:00 - 16:30	*Coffee Break*
16:30 - 18:30	**Session 4: Oral Presentation**
20:30 - 23:00	*Social Dinner*
26 March 2014 - Wednesday	
08:30 - 16:00	***REGISTRATION***
09:00 - 11:00	**Session 5: Oral Presentation**
11:00 - 11:30	*Coffee Break*
11:30 - 13:00	**Session 6: Oral Presentation**
13:00 - 14:30	*Lunch*
14:30 - 15:30	**Session 7: Poster Presentation**
15:30 - 16:00	*Discussion and Coffee Farewell*
16:00	**Closure of Meeting**

COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

Background and goals

About COST Action TD1105 EuNetAir

COST Action TD 1105 EuNetAir (www.cost.eunetair.it), a Concerted Action on *New Sensing Technologies for Air-Pollution Control and Environmental Sustainability*, is a running Networking funded in the framework *European Cooperation in the field of Scientific and Technical Research* (COST) during 2012-2016.

The main objective of the Concerted Action is to develop new sensing technologies for Air Quality Control at integrated and multidisciplinary scale by coordinated research on nanomaterials, sensor-systems, air-quality modelling and standardised methods for supporting environmental sustainability with a special focus on Small and Medium Enterprises.

This international Networking, coordinated by ENEA (Italy), includes over 75 big institutions from 28 COST Countries (EU-zone: *Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, The Former Yugoslav Republic of Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom*) and 7 Non-COST Countries (extra-Europe: *Australia, Canada, China, Morocco, Russia, Ukraine, USA*) to create a S&T critical mass in the environmental issues.

About the Second International Workshop of COST Action TD1105 at Brindisi, 25-26 March 2014

The **2nd International Worskhop** on *New Sensing Technologies for Indoor and Outdoor Air Quality Control* will be held at ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Brindisi Research Center (Italy). This second workshop of the Action TD1105 *EuNetAir* follows the first organized at Barcelona (20 June 2013) as Satellite Event inside *Transducers 2013 - Eurosensors XXVII*, as planned in the MoU roadmap.

The **core-issues of the COST Action TD1105** on the new sensing technologies for indoor and outdoor monitoring and air quality control will be surveyed by Action partners with emphasis at sensor materials, functional materials, nanotechnologies for gas sensors, low-cost and low-power chemical sensors, portable systems, sensor-instrumentations, air-pollution modelling, methods, measurements and protocols for air quality control and environmental monitoring.

Speakers, experts, practitioners, stakeholders and other specialists from environmental agencies, academy and industry from Europe will be encouraged to participate and give a Talk on current state-of-art on the environmental research and existing critical issues in the ongoing Revision of the ***Air Quality Directive 2008/50/EC*** and ***EU Thematic Strategy on Air Pollution***. Fruitful discussions between Action TD1105 participants, international experts, regional managers, speakers, including international institutional organizations delegates and policy-makers are strongly expected. A strong impact on focusing of the critical environmental issues related to the new sensing technologies for indoor and outdoor monitoring and air quality control would be mutual benefit.

The accepted contributions (Oral/Poster) will be collected in a ***Booklet*** to be electronically distributed to the participants. Researchers, Scientists, External Experts, Managers, Early Stage Researchers will be involved from COST Countries signing Memorandum of Understanding (MoU) in open and balanced way.

More Information

- Michele Penza, MC Chair/Proposer of *COST Action TD1105 EuNetAir*
  ENEA - PO BOX 51 Br-4, I-72100 Brindisi - ITALY - michele.penza@enea.it
- Marco Alvisi, Action SIG1 Leader and Local Organizing Committee Chair
  ENEA - PO BOX 51 Br-4, I-72100 Brindisi - ITALY - marco.alvisi@enea.it

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Tuesday, 25 March 2014

COST Action TD1105 EuNetAir WORKSHOP

Palazzo Nervegna-Granafei (City Mayor Headquarters)
Via Duomo, 20 - 72100 Brindisi, Italy

08:30 - 18:00	**COST Event Registration**
09:00 - 09:30	***Welcome Address*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
	Welcome: Mayor of City of Brindisi *Mimmo Consales*, Mayor of Brindisi, Italy
	Welcome: ENEA *Leander Tapfer*, Head of Technical Unit for Materials Technologies - Brindisi Research Center, ENEA, Brindisi, Italy
	Welcome: Puglia Regional Government Technical Representative *Francesco Surico*, InnovaPuglia - Puglia Government for Economic Development, Bari, Italy
09:30 - 11:00	***Session 1 - Plenary Session*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
09:30 - 10:00	**COST Action TD1105: European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability. Overview and Plans of COST Action TD1105** *Michele Penza*, Action Chair, ENEA, Brindisi, Italy
10:00 - 10:30	**Artificial Olfaction Systems for Air-Quality Monitoring Applications** *Krishna Persaud*, The University of Manchester, School of Chemical Engineering and Analytical Science, Manchester, United Kingdom
10:30 - 11:00	**Can Air Quality Low-cost Sensors Help Citizens to Create Smart Cities ?** *Nuria Castell-Balaguer*, NILU - Norwegian Institute for Air Research, Kjeller, Norway
11:00 - 11:30	**Coffee Break**
11:30 - 13:00	***Session 2 - Clean Air for Smart Cities*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
11:30 - 12:00	**Smart Cities: An Opportunity for Sustainability** *Mauro Annunziato*, European Energy Research Alliance Smart Cities Delegate, ENEA, Rome, Italy
12:00 - 12:20	**Low Cost Sensor Networks for Urban Air-Quality Monitoring Applications** *Vivien Bright*, University of Cambridge, Centre for Atmospheric Science, Cambridge, UK
12:20 - 12:40	**Enabling High Resolution Urban Pollution Monitoring through Mobile Sensor Networks** *Adrian Arfire*, EPFL, Lausanne, Switzerland
12:40 - 13:00	**Development of a Low-cost Mobile Sensor-System for Participatory Measurements of Urban Air Quality** *Jan Peters*, VITO, Mol, Belgium
13:00 - 14:30	**Lunch Break**

14:30 - 16:00	***Session 3 - Sensing Technologies for Indoor Applications*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
14:30 - 15:00	**Chemical Sensors for the Detection and Quantification of Indoor Air Pollutants** *Thu-Hoa Tran-Thi*, CEA-CNRS, CEA-Saclay, Francis Perrin Laboratory URA 2453, 91191 Gif-sur-Yvette, France
15:00 - 15:20	**Selective Detection of Indoor VOCs Using a Virtual Gas Sensor Array** *Martin Leidinger*, Saarland University, Saarbrucken, Germany
15:20 - 15:40	**Indoor Environment and Health in Elderly Care Centers: The GERIA Project** *Joao Paulo Teixeira*, National Institute of Health, Porto, Portugal
15:40 - 16:00	**Indoor Air Quality Assessment: Towards a Better Protection of People** *Carlos Borrego*, IDAD - Institute of Environment and Development, Aveiro, Portugal

16:00 - 16:30	**Coffee Break**

16:30 - 18:30	***Session 4 - Methods and Applications for Environmental Sustainability*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
16:30 - 16:50	**COST Action ES1002 WIRE: Weather Intelligence for Renewable Energies** *Annamaria Sempreviva*, Vice-Chair COST Action ES1002, CNR - Institute of Atmospheric Science and Climate, Lamezia Terme, Italy
16:50 - 17:10	**The Urban Control Center: An ICT Platform for Smart Cities in Italy** *Paolo Deidda*, IBM Italia SpA, Rome, Italy
17:10 - 17:30	**The Urban Control Center: KPIs for Decisions Support of Smart Cities in Italy** *Mariagrazia Dotoli and Raffaele Carli*, Politecnico di Bari, Bari, Italy
17:30 - 17:50	**Development of a Portable Sensor-System for Air Quality Monitoring** *Domenico Suriano and Michele Penza*, ENEA, Brindisi, Italy
17:50 - 18:10	**Air Quality in Spanish Cities: First Steps in Smart Sensors Validation** *Mariacruz Minguillon*, CSIC-IDAEA, Barcelona, Spain
18:10 - 18:30	**Particulate Matter in Different Atmospheric Reservoirs: Copenhagen, a Highly Populated Area versus Station Nord, a Remote High Arctic Site** *Andreas Massling,* Aarhus University, Roskilde, Denmark

20:30 - 23:00	**Social Dinner**

Wednesday, 26 March 2014

COST Action TD1105 EuNetAir WORKSHOP

Palazzo Nervegna-Granafei (City Mayor Headquarters)
Via Duomo, 20 - 72100 Brindisi, Italy

08:30 - 16:00	**COST Event Registration**
09:00 - 11:00	***Session 5 - Advanced Materials for Chemical Sensors*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
09:00 - 09:30	**Towards Zero-Power Gas Detection Systems Based on Single Nanowires** *Albert Romano-Rodriguez*, Universitat de Barcelona, Department of Electronics, Barcelona, Spain
09:30 - 10:00	**Gas Sensing with Epitaxial Graphene on Silicon Carbide: Performance Tuning for Air Quality Control** *Jens Eriksson[2], D. Puglisi[2], C. Bur[1,2], M. Andersson[2], A. Lloyd Spetz[2], and A. Schütze[1]*, [1]Saarland University, Saarbrucken, Germany; [2]Linkoping University, Linkoping, Sweden
10:00 - 10:20	**Sensing Devices based on Metallophthalocyanine and Phthalocyanine/Nanocarbons Hybrid Materials: Application to the Aromatic Hydrocarbon Detection** *Jerome Brunet*, Universitè Blaise Pascal, LASMEA-CNRS, Aubiere, France
10:20 - 10:40	**Detection of Low Concentrations of Volatile Organic Compounds with SiC-Field Effect Transistors** *Donatella Puglisi[2], C. Bur[1,2], J. Eriksson[2], M. Andersson[2], A. Lloyd Spetz[2], and A. Schütze[1]*, [1]Saarland University, Saarbrucken, Germany; [2]Linkoping University, Linkoping, Sweden
10:40 - 11:00	**Electrodeposited Nanostructured Materials for Gas Sensing** *Nicola Cioffi*, University of Bari, Department of Chemistry, Bari, Italy
11:00 - 11:30	**Coffee Break**
11:30 - 13:00	***Session 6 - Sensors and Systems for Air Quality Control*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
11:30 - 12:00	**Low-Power and Portable AlGaN/GaN Based Sensor-Systems for Air Monitoring** *Rob van Schaijk*, IMEC Holst-Centre, Eindhoven, The Netherlands
12:00 - 12:20	**CMOS-based Sensors for Ubiquitous Gas Detection - Challenges and Opportunities** *Mohamed Foysol Chowdhury*, Cambridge CMOS Sensors Ltd, Cambridge, UK
12:20 - 12:40	**Graphene-based Gas Sensors** *Tiziana Polichetti*, ENEA, Portici (Naples), Italy
12:40 - 13:00	**Computational Approaches to Wireless Chemical Sensing Challenges** *Saverio De Vito*, ENEA, Portici (Naples), Italy
13:00 - 14:30	**Lunch Break**

14:30 - 15:30	***Session 7 - Poster Session*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*

Posters will be presented by Quick Presentations (8-10 minutes, max 10 templated slides) by presenters, preferably Early Stage Researchers. Posters are listed by theme and as-received.

MATERIALS, SENSORS AND SYSTEMS FOR AIR QUALITY MONITORING

P01	**Electrophoretic Au NPs Deposition on Carbon Nanotubes for NO_2 Sensors** *Elena Dilonardo (1), Michele Penza (2), Marco Alvisi (2), Domenico Suriano (2), Riccardo Rossi (2), Francesco Palmisano (1), Luisa Torsi (1), Nicola Cioffi (1)*; (1)University of Bari, Bari, Italy; (2)ENEA, Brindisi, Italy
P02	**Pd-Doped ZnO Nanorods for VOCs Sensing** *Sadullah Ozturk (1), Zafer Z. Ozturk (1), Marco Alvisi (2), Domenico Suriano (2), Michele Penza (2),* (1)GEBZE Institute of Technology, Kocaeli, Turkey; (2)ENEA, Brindisi, Italy
P03	**ZnO Nanorods for Gas Sensors** *R. Yatskiv, M. Verde, J. Grym*, Synthesis and characterization of nanomaterials, Institute of Photonics and Electronics AVCR, Prague, Czech Republic
P04	**Nanostructured Schottky Contacts for Gas Sensors** *J. Grym, R. Yatskiv, O. Cernohorsky, M. Verde*, Synthesis and characterization of nanomaterials, Institute of Photonics and Electronics AVCR, Prague, Czech Republic

15:30 - 16:00	***Discussion on R&I Needs of COST Action TD1105*** *Chairperson: Michele Penza, Action Chair - ENEA, Brindisi, Italy*
15:30 - 15:40	**Research & Innovation Priorities from COST Action TD1105** *Michele Penza*, ENEA, Brindisi, Italy
15:40 - 15:50	**Research & Innovation Needs from COST Action TD1105** *Marco Alvisi*, ENEA, Brindisi, Italy
15:50 - 16:00	**Discussions from COST Action TD1105 Partners/Stakeholders**

16:00	**Closure of COST Action TD1105 *EuNetAir* WORKSHOP**

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

SECOND INTERNATIONAL WORKSHOP on New Sensing Technologies for Indoor and Outdoor Air Quality Control

Brindisi (Italy), 25 - 26 March 2014

Palazzo Nervegna-Granafei (City Mayor Headquarters)
Via Duomo, 20 - 72100 Brindisi, Italy

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability








Action Second Workshop Programme Committee

Michele Penza, ENEA, Brindisi, Italy
Marco Alvisi, ENEA, Brindisi, Italy
Anita Lloyd Spetz, Linkoping University, Sweden
Juan Ramon Morante, IREC and Universitat de Barcelona, Spain
Eduard Llobet, Universitat Roviri I Virgili, Tarragona, Spain
Andreas Schuetze, Saarland University, Germany
Ole Hertel, Aarhus University, Denmark
Ingrid Bryntse, SenseAir AB, Sweden
Jan Theunis, VITO, Belgium

Local Organizing Committee

Marco Alvisi, ENEA, Brindisi, Italy - *Local Chair*
Domenico Suriano, ENEA, Brindisi, Italy - *Local Member*
Annamaria Demarinis Loiotile, University of Bari, Italy - *Secretary*
Juliane Rossbach, Eurice, Saarbrucken, Germany - *Grant Holder*
Corinna Hahn, Eurice GmbH, Saarbrucken, Germany - *Grant Holder*

URL: www.cost.eunetair.it

COST Action TD1105 EuNetAir Steering Committee

Michele Penza, ENEA, Brindisi, Italy - *Action Chair*
Anita Lloyd Spetz, Linkoping University, Sweden - *Action Vice-Chair*
Juan Ramon Morante, IREC, Spain
Andreas Schuetze, Saarland University, Germany
Ole Hertel, Aarhus University, Denmark
Ingrid Bryntse, SenseAir AB, Sweden
Jan Theunis, VITO, Belgium
Marco Alvisi, ENEA, Brindisi, Italy
Gianluigi De Gennaro, University of Bari, Italy
Fabio Galatioto, Newscastle University, UK
Ralf Moos, University of Bayreuth, Germany
Mar Viana, CSIC-IDAEA, Barcelona, Spain
Iveta Steinberga, University of Latvia, Riga, Latvia
Roberto Simmarano, Sensichips, Aprilia (Rome), Italy
Julian Gardner, University of Warwick, UK
Rod Jones, University of Cambridge, UK
Giorgio Sberveglieri, University of Brescia, Italy
Eduard Llobet, Universitat Roviri I Virgili, Tarragona, Spain
Thomas Kuhlbusch, IUTA eV, Duisburg, Germany
Albert Romano-Rodriguez, Universitat de Barcelona (UB), Spain
Annamaria Demarinis Loiotile, University of Bari, Italy - *Secretary*
Corinna Hahn, Eurice GmbH, Saarbrucken, Germany - *Grant Holder*

COST is supported by the EU Framework Programme
European Science Foundation — ESF provides the COST Office through a European Commission contract

WELCOME ADDRESS

This is a great honor and my pleasure to chair and welcome to ALL PARTICIPANTS of the **Second International Workshop** of our COST Action TD1105 *European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability - EuNetAir*.

This COST Workshop - held on 25-26 March 2014 - on ***New Sensing Technologies for Indoor and Outdoor Air Quality Control*** is supported by **Municipality of Brindisi** and hosted at **Palazzo Nervegna-Granafei**, Representative Headquarters of Municipality of Brindisi (Italy) with the Local Organizing Support from **ENEA**, *Brindisi Research Center*.

This **Second Workshop** follows the first *COST Workshop in Barcelona* (20 June 2013), and it is attended from at least 40 Participants and includes 7 Sessions with 2 Keynote Speakers, 6 Invited Speakers, 19 Oral Speakers and 4 Poster Presenters from at least 14 COST Countries. An international Advisory Board (*Steering Committee*) composed by 22 Members has served with S&T inputs to define Workshop Programme. *Female participants* are as 28% and *Male participants* are as 72% with a quota of *Early Stage Researchers* as 35%.

The concerted COST Action TD1105 *EuNetAir* - related to R&D issues of the air quality monitoring including environmental technologies, nanomaterials, functional materials, gas sensors, smart systems, air-pollution modelling, measurements, methods, standards and protocols - is very pleased to connect international specialists and excellent scientists to create a networking of Pan-European R&D platform from 28 COST Countries and 7 Non-COST Countries. Most part of COST Countries are represented in this Workshop.

Special thanks to **COST Office** Representative (Dr. Deniz Karaca, ESSEM Science Officer) involved as Science Officer in our Action. This COST interest in Brindisi Workshop is expressed by a valuable *Letter of Support* signed by *COST Office Director* (Dr. Monica Dietl) through *COST Science Operations Head* (Prof. Tatiana Kovacikova) in Brussels.

On behalf of the Action Management Committee, I would like to thank ALL Workshop **Participants**, **Grant Holder** and **Action Scientific Secretary**, **Local Organizing Committee** by ENEA, **InnovaPuglia** as Local Economic Development Office from *Regione Puglia*, and **Municipality of Brindisi**, represented by *Mayor of Brindisi City*, to host and support this Action Workshop, in order to give us the opportunity to disseminate the results of the COST Action TD1105 *EuNetAir* towards a wide international targeted audience involved in the Air Quality Control, with special focus on *Clean Air for Smart Cities*, as local hot-issue. With their valuable scientific work and management, kind availability and great enthusiasm will make our Action Workshop very successful !

Enjoy your *EuNetAir* COST Workshop at Palazzo Nervegna-Granafei in Brindisi !

Brindisi, 18 March 2014

Michele Penza, ENEA, Brindisi, Italy
COST Action TD1105 Chair
michele.penza@enea.it

EuNetAir COST Action TD1105 Logo

LIST OF PRESENTERS

Welcome Address Session

Welcome Address from Mayor of City of Brindisi
Mimmo Consales, Mayor of Brindisi, Italy

Welcome Address from ENEA
Leander Tapfer, Head of Technical Unit for Materials Technologies - Brindisi Research Center, ENEA, Brindisi, Italy

Welcome Address from Puglia Regional Government Technical Representative
Francesco Surico, InnovaPuglia - Puglia Government for Economic Development, Bari, Italy

Session 1 – Plenary Session

COST Action TD1105: European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability. Overview and Plans of COST Action TD1105
Michele Penza, Action Chair, ENEA, Brindisi, Italy

Artificial Olfaction Systems for Air-Quality Monitoring Applications
Krishna Persaud, The University of Manchester, School of Chemical Engineering and Analytical Science, Manchester, United Kingdom

Can Air Quality Low-cost Sensors Help Citizens to Create Smart Cities?
Nuria Castell-Balaguer, NILU - Norwegian Institute for Air Research, Kjeller, Norway

Session 2 - Clean Air for Smart Cities

Smart Cities: An Opportunity for Sustainability
Mauro Annunziato, European Energy Research Alliance Smart Cities Delegate, ENEA, Rome, Italy

Low Cost Sensor Networks for Urban Air-Quality Monitoring Applications
Vivien Bright, University of Cambridge, Centre for Atmospheric Science, Cambridge, UK

Enabling High Resolution Urban Pollution Monitoring through Mobile Sensor Networks
Adrian Arfire, EPFL, Lausanne, Switzerland

Development of a Low-cost Mobile Sensor-System for Participatory Measurements of Urban Air Quality
Jan Peters, VITO, Mol, Belgium

Session 3 - Sensing Technologies for Indoor Applications

Chemical Sensors for the Detection and Quantification of Indoor Air Pollutants
Thu-Hoa Tran-Thi, CEA-CNRS, CEA-Saclay, Francis Perrin Laboratory URA 2453, 91191 Gif-sur-Yvette, France

Selective Detection of Indoor VOCs Using a Virtual Gas Sensor Array
Martin Leidinger, Saarland University, Saarbrucken, Germany

Indoor Environment and Health in Elderly Care Centers: The GERIA Project
Joao Paulo Teixeira, National Institute of Health, Porto, Portugal

Indoor Air Quality Assessment: Towards a Better Protection of People
Carlos Borrego, IDAD - Institute of Environment and Development, Aveiro, Portugal

Session 4 - Methods and Applications for Environmental Sustainability

COST Action ES1002 WIRE: Weather Intelligence for Renewable Energies
Annamaria Sempreviva, Vice-Chair COST Action ES1002, CNR - Institute of Atmospheric Science and Climate, Lamezia Terme, Italy

The Urban Control Center: An ICT Platform for Smart Cities in Italy
Paolo Deidda, IBM Italia SpA, Rome, Italy

The Urban Control Center: KPIs for Decisions Support of Smart Cities in Italy
Mariagrazia Dotoli and Raffaele Carli, Politecnico di Bari, Bari, Italy

Development of a Portable Sensor-System for Air Quality Monitoring
Domenico Suriano and Michele Penza, ENEA, Brindisi, Italy

Air Quality in Spanish Cities: First Steps in Smart Sensors Validation
Mariacruz Minguillon, CSIC-IDAEA, Barcelona, Spain

Particulate Matter in Different Atmospheric Reservoirs: Copenhagen, a Highly Populated Area versus Station Nord, a Remote High Arctic Site
Andreas Massling, Aarhus University, Roskilde, Denmark

Session 5 - Advanced Materials for Chemical Sensors

Towards Zero-Power Gas Detection Systems Based on Single Nanowires
Albert Romano-Rodriguez, Universitat de Barcelona, Department of Electronics, Barcelona, Spain

Gas Sensing with Epitaxial Graphene on Silicon Carbide: Performance Tuning for Air Quality Control
Jens Eriksson[2], D. Puglisi[2], C. Bur[1,2], M. Andersson[2], A. Lloyd Spetz[2], and A. Schütze[1], [1]Saarland University, Saarbrucken, Germany; [2]Linkoping University, Linkoping, Sweden

Sensing Devices based on Metallophthalocyanine and Phthalocyanine/Nanocarbons Hybrid Materials: Application to the Aromatic Hydrocarbon Detection
Jerome Brunet, Universitè Blaise Pascal, LASMEA-CNRS, Aubiere, France

Detection of Low Concentrations of Volatile Organic Compounds with SiC-Field Effect Transistors
Donatella Puglisi[2], C. Bur[1,2], J. Eriksson[2], M. Andersson[2], A. Lloyd Spetz[2], and A. Schütze[1], [1]Saarland University, Saarbrucken, Germany; [2]Linkoping University, Linkoping, Sweden

Electrodeposited Nanostructured Materials for Gas Sensing
Nicola Cioffi, University of Bari, Department of Chemistry, Bari, Italy

Session 6 - Sensors and Systems for Air Quality Control

Low-Power and Portable AlGaN/GaN Based Sensor-Systems for Air Monitoring
Rob van Schaijk, IMEC Holst-Centre, Eindhoven, The Netherlands

CMOS-based Sensors for Ubiquitous Gas Detection - Challenges and Opportunities
Mohamed Foysol Chowdhury, Cambridge CMOS Sensors Ltd, Cambridge, UK

Graphene-based Gas Sensors
Tiziana Polichetti, ENEA, Portici (Naples), Italy

Computational Approaches to Wireless Chemical Sensing Challenges
Saverio De Vito, ENEA, Portici (Naples), Italy

Session 7 - Poster Session

MATERIALS, SENSORS AND SYSTEMS FOR AIR QUALITY MONITORING

P01: **Electrophoretic Au NPs Deposition on Carbon Nanotubes for NO2 Sensors**
Elena Dilonardo (1), Michele Penza (2), Marco Alvisi (2), Domenico Suriano (2), Riccardo Rossi (2), Francesco Palmisano (1), Luisa Torsi (1), Nicola Cioffi (1); (1)University of Bari, Bari, Italy; (2)ENEA, Brindisi, Italy

P02: **Pd-Doped ZnO Nanorods for VOCs Sensing**
Sadullah Ozturk (1), Zafer Z. Ozturk (1), Marco Alvisi (2), Domenico Suriano (2), Michele Penza (2), (1)GEBZE Institute of Technology, Kocaeli, Turkey; (2)ENEA, Brindisi, Italy

P03: **ZnO Nanorods for Gas Sensors**
R. Yatskiv, M. Verde, J. Grym, Synthesis and characterization of nanomaterials, Institute of Photonics and Electronics AVCR, Prague, Czech Republic

P04: **Nanostructured Schottky Contacts for Gas Sensors**
J. Grym, R. Yatskiv, O. Cernohorsky, M. Verde, Synthesis and characterization of nanomaterials, Institute of Photonics and Electronics AVCR, Prague, Czech Republic

Discussion on R&I Needs of COST Action TD1105

Research & Innovation Priorities from COST Action TD1105
Michele Penza, ENEA, Brindisi, Italy

Research & Innovation Needs from COST Action TD1105
Marco Alvisi, ENEA, Brindisi, Italy

Discussions from COST Action TD1105 Partners/Stakeholders

ABSTRACTS
OF
INVITED TALKS

Invited Talk

COST ACTION TD1105 ON NEW SENSING TECHNOLOGIES FOR AIR-POLLUTION CONTROL AND ENVIRONMENTAL SUSTAINABILITY: OVERVIEW AND PLANS OF ACTION

M. Penza
ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Technical Unit for Materials Technologies-Brindisi Research Center, PO Box 51 Br-4, I-72100 Brindisi, Italy. Email: michele.penza@enea.it

Abstract

This is a short overview of the COST Action TD1105 EuNetAir - *European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability* - funded in the framework *European Cooperation in the field of Scientific and Technical Research* (COST) during the period 2012-2016.

The main objective of the Concerted Action is to develop new sensing technologies for Air Quality Control at integrated and multidisciplinary scale by coordinated research on nanomaterials, sensor-systems, air-quality modelling and standardised methods for supporting environmental sustainability with a special focus on Small and Medium Enterprises.

This international Networking, coordinated by ENEA (Italy), includes over 80 big institutions and over 170 international experts from 28 COST Countries (EU-zone: *Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, The Former Yugoslav Republic of Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom*) and 7 Non-COST Countries (extra-Europe: *Australia, Canada, China, Morocco, Russia, Ukraine, USA*) to create a S&T critical mass in the environmental issues.

This COST Action [1, 2] (see logo in Fig. 1) will focus on a new detection paradigm based on sensing technologies at low cost for Air Quality Control (AQC) and set up an interdisciplinary top-level coordinated network to define innovative approaches in sensor nanomaterials, gas sensors, devices, wireless sensor-systems, distributed computing, methods, models, standards and protocols for environmental sustainability within the European Research Area (ERA).

The state-of-the-art showed that research on innovative sensing technologies for AQC based on advanced chemical sensors and sensor-systems at low-cost, including functional materials and nanotechnologies for eco-sustainability applications, the outdoor/indoor environment control, olfactometry, air-quality modelling, chemical weather forecasting, and related standardisation methods is performed already at the international level, but still needs serious efforts for coordination to boost new sensing paradigms for research and innovation. Only a close multidisciplinary cooperation will ensure cleaner air in Europe and reduced negative effects on human health for future generations in smart cities, efficient management of green buildings at low CO_2 emissions, and sustainable economic development.

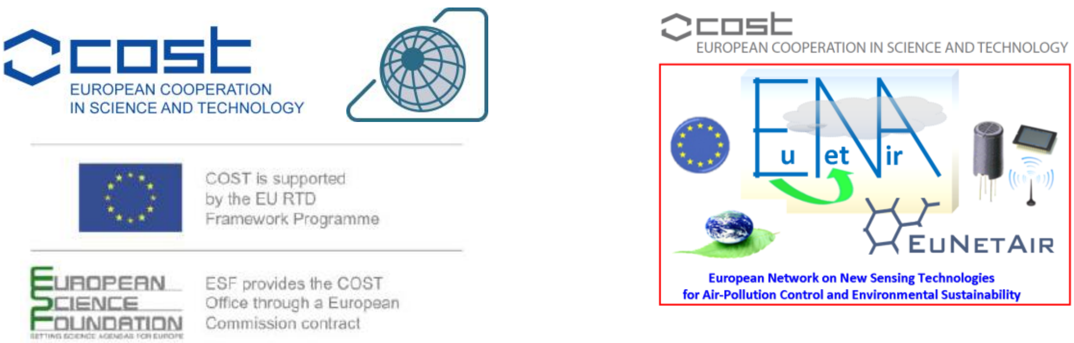

Figure 1. COST Office, ESSEM Domain and Action TD1105 EuNetAir Logo.

The aim of the Action is to create a cooperative network to explore new sensing technologies for low-cost air-pollution control through field studies and laboratory experiments to transfer the results into preventive real-time control practices and global sustainability for monitoring climate changes and outdoor/indoor energy efficiency. Establishment of such a European network, involving Non-COST key-experts, will enable EU to develop world capabilities in urban sensor technology based on cost-effective nanomaterials and contribute to form a critical mass of researchers suitable for cooperation in science and technology, including training and education, to coordinate outstanding R&D and promote innovation towards industry, and support policy-makers. Main objectives of Action are listed, but not limited to:

- to establish a top-level Pan-European multidisciplinary R&D platform on new sensing paradigm for AQC contributing to sustainable development, green-economy and social welfare
- to create collaborative research teams in the ERA on the new sensing technologies for AQC in an integrated approach to avoid fragmentation of the research efforts
- to train Early Stage Researchers (ESR) and new young scientists in the field for supporting competitiveness of European industry by qualified human potential
- to promote gender balance and involvement of ESR in AQC
- to disseminate R&D results on AQC towards industry community and policy makers as well as general public and high schools.

The Workplan is organized in four complementary Working Groups (WGs), each devoted to a progressive development of synthesis, characterization, fabrication, integration, prototyping, proof-of-concepts, modeling, measurements, methods, standards, tests and application aspects. The four WGs with the specific objectives are:

- **WG1**: *Sensor materials and nanotechnology*
- **WG2**: *Sensors, devices and sensor-systems for AQC*
- **WG3**: *Environmental measurements and air-pollution modeling*
- **WG4**: *Protocols and standardisation methods*

This Action will focus on the study of sensor nanomaterials and nanotechnologies exhibiting unique properties in terms of chemical and thermal stability, high sensitivity, selectivity. Nanosize effects of functional materials will be explored for integration in the gas sensors at low power-consumption. Furthermore, specific nanostructures with tailored sensing properties will be developed for gas sensors and sensor-systems with advanced functionalities.

Selected high-quality research products and innovative technologies developed by the partnership of COST Action TD1105 are shown in the Figure 2.

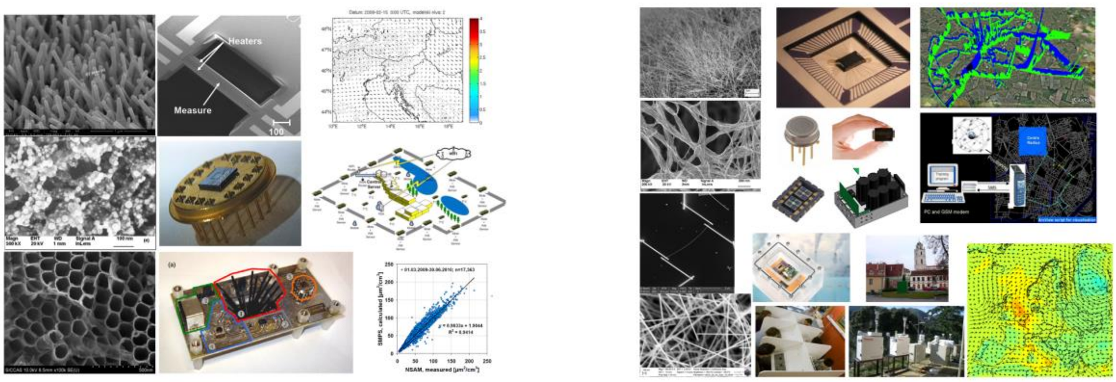

Figure 2. Selected R&D technological products developed by some partners (academia, research institutes, agencies, industry) involved in the COST Action TD1105 EuNetAir. Courtesy from EuNetAir partnership.

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2. Action website: http://www.cost.eunetair.it

Invited Talk

ARTIFICIAL OLFACTION SYSTEMS FOR AIR-QUALITY MONITORING APPLICATIONS

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Abstract

The effects of indoor air quality on human health are of increasing concern (Jones et al., 2002). Air quality studies conducted in London demonstrated that a large proportion of homes (18%) exceeded one or more of the WHO guideline values for carbon monoxide (Croxford et al., 2006). CO concentrations indoors are highest in homes that have faulty or poorly vented combustion appliances, but also homes where smoking takes place Similarly, concentrations of nitrogen dioxide and sulphur dioxide can be significant in the indoor and outdoor environment and are considered as being hazardous to health. Volatile organic compounds are a group of chemicals that are both diverse and numerous, have many sources and are also potentially harmful to human health. These substances can arise from sources including paints, varnishes, solvents, and preservatives (Jones et al., 2002).

Arrays of gas sensors are useful in the context of environmental monitoring, as the data captured can be processed in a multivariate way in analogy to artificial olfactory systems. This paper introduces a system for continuously monitoring these pollutant gases and vapours in the home.

Materials and Methods

Air quality monitoring was performed using sensor units developed by a team at CEAS, The University of Manchester (Fiadzomor et al., 2011). Air quality monitoring is conducted to collect primary emission data from homes utilising gas and electricity for heating and cooking. The sensor units measure SO_2 (sulphur dioxide), NO_2 (nitrogen dioxide), CO (carbon monoxide), CO_2 (carbon dioxide), TVOCs (total volatile organic compounds), relative humidity and temperature. Each unit enables the measuring of gas emissions every 60 seconds over a 14 day period using a micro-pump to draw sample air from the environment across sensors. The data are stored ready for analysis on completion of each monitoring period. This approach is further assisted through the use of detailed user diaries that indicate key cooking and heating events during the monitoring. Two sensor units are placed within the house (kitchen and living room) and one outdoors in the vicinity of the home.

Results

Figure 1 shows Total VOC concentrations measured in a home over the summer period over

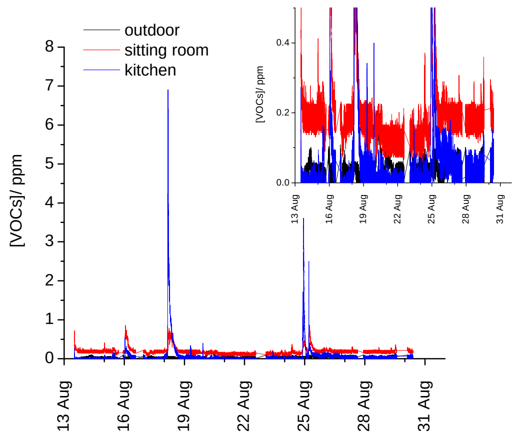

Figure 1 Total VOC's measured over a two week period.

two weeks, while Figure 2 shows the large differences of CO_2 concentrations found outside the house, within the kitchen and in the sitting room.

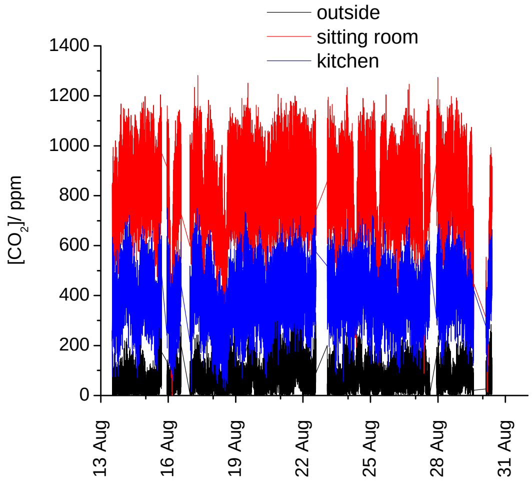

Figure 2 CO_2 concentrations in different locations inside and outside the house

Comparing the indoor air monitoring results obtained from a sample of houses that were recorded during the summer as well as in the winter, it was found that the 'all gas' fuelled houses studied were similar in terms of the concentration changes in CO, CO_2 and NO_2. A greater increase in CO to the indoor environment is evident during cooking events especially within the 'all gas' homes and this appears to match the households use of the gas oven or hob. Moreover, winter results from all homes indicate high indoor concentrations as would be expected with lower ventilation rates - this is particularly true for CO.
Further analysis shows variation in CO and NO_2 within the 'all gas' homes, again possibly related to the use of natural gas during cooking. Elsewhere, temperature and humidity changes are moderately consistent across all homes and the same is true for SO_2 concentrations.

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COST Action TD1105 *EuNetAir*
2nd International Workshop *EuNetAir*, Brindisi (Italy), 25-26 March 2014

Invited Talk

CAN LOW-COST AIR QUALITY SENSORS HELP CITIZENS TO CREATE SMART CITIES?

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Abstract

In Europe, the majority of the population lives in areas where air quality levels frequently exceed WHO's ambient air quality guidelines (EEA, 2013). Current air pollution monitoring networks consist of few stations equipped with highly technologically advanced but costly air quality monitors, which provide accurate data, but only in few, static locations (Castell et al., 2013). In addition, a number of cities has capabilities to provide spatially distributed information using models, but in general, data at the citizen level is currently scarce or non-existent. This is a severe limitation in important cases when individual information is required, e.g., for assessment of human exposure to atmospheric pollutants or to provide advice to special groups with high exposure risks.

The emergence of lower-cost, easy-to-use, portable air pollution monitors (sensor platforms) allowing observations at high spatial resolution in real-time provides new opportunities to enhance our existing air quality monitoring networks. Sensor devices are currently available to monitor a range of air pollutants and new devices are continually being introduced (Aleixandre and Gerboles, 2012). However, challenges remain regarding the use of sensors and sensor data, mainly data quality and derivation of meaningful information from datasets (Snyder et al., 2013).

This paper presents the efforts taking place in the city of Oslo, Norway, with the campaign results expected by the end of 2015. The work is being developed under two related EU-funded projects: CITI-SENSE and Citi-Sense-MOB. Key to both projects is the use of novel lower-cost sensors and Information and Communication Technologies (ICT) to enable citizens to directly contribute to environmental monitoring.

CITI-SENSE builds on the concept of Citizens' Observatories to empower citizens to contribute to environmental governance, and enable them to support community-based decision-making. CITI-SENSE will develop, test, demonstrate and validate a community-based environmental monitoring and information system using low-cost sensors and novel Earth Observation applications.

Citi-Sense-MOB will develop new mobile services to support green growth and sustainable development in the Oslo region. The project aims at providing citizens, and other stakeholders with information on environmental quality. In order to accomplish the goal of creating a dynamic city infrastructure for real-time urban environment and health management, Citi-Sense-MOB will create and use innovative technology to continuously measure, share and communicate environmental data with both citizens and public authorities.

Figure 1 illustrates the common methodology used in both projects. The measuring system is composed of low-cost sensors deployed in the city (e.g., streetlamp, building balconies, etc.), carried by people and mounted on mobile platforms (e.g., buses, bicycles, cars, etc.). The continuously gathered data are then transmitted to a server for processing (e.g., automatic quality control, generation of maps and graphics, etc.). The processed data are sent back to the users (i.e., citizens, cyclists, city authorities, bus companies, etc.) and presented in an user-friendly and visually informative layout using both web solutions and mobile phone apps.

Figure 1. CITI-SENSE and Citi-Sense-MOB system overview - Oslo case study (COT: citizens' observatories toolbox; VGI: Volunteered Geographical Information; GNSS: Global Navigation Satellite System).

CITI-SENSE and Citi-Sense-MOB will test how new technologies, such as low-cost sensors and innovative ICT, can help improve city management using near-real-time measurements. They will further test the feasibility of different sensor technologies and approaches and explore how these data contribute to air quality monitoring and complement existing air quality monitoring networks. By exploring how these data can contribute to a more comprehensive understanding of air quality monitoring, we hope to show that complementing existing air quality monitoring networks is not just feasible, but highly desirable.

CITI-SENSE and Citi-Sense-MOB projects are setting the stage for innovative developments in air quality monitoring and individual exposure assessment. The data gathered from the projects will be made available using Open Linked Data standards, and will thus contribute to a range of novel services in monitoring, transport, personal well-being and city planning.

Acknowledgments

Citi-Sense-MOB (http://www.citi-sense-mob.eu) is a collaborative project partly funded by The European Mobile and Mobility Industries Alliance (EMMIA).
CITI-SENSE (http://www.citi-sense.eu) is a Collaborative Project partly funded by the EU FP7-ENV-2012 under grant agreement no 308524.

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Invited Talk

The Urban Networks Approach in the EERA European Smart Cities Joint Programme

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Abstract
According to a recent European Commission survey, about seventy percent of energy consumption takes places in the cities. A crucial element in reducing this impact - while of course maintaining or improving the quality of the functions offered to citizens - is conceiving of a city as a complex set of interlinked networks. Those can be infrastructure-related (villages, neighbourhoods, roads), material (flows of goods, vehicles, water or energy) or intangible (data communication). This concept of "interconnected urban networks" is crucial to understanding and adapting energy consumption, storage and production in urban areas. The basic challenge of making cities smart is therefore a matter of integrating sustainability and connectivity, taking into account the dynamic behaviour of the system and fluctuating consumption and production patterns. At present many new technologies and applications are being developed that will improve the interconnection among networks; that allow for the delivery of innovative multifunctional services such as the optimal management of energy consumption, storage and local grid to mitigate environmental impact; or that offer services related to mobility, sustainability education.

Each city can be considered as an organism, with its complexity and its interlinked networks, also and maybe primarily at energy level. Each city has its own energy metabolism, characterised by energy production, storage and consumption with their corresponding "interconnected networks": they can work properly by means of suitable interconnected sensor networks to collect data aimed at optimizing the operational logics of a smart and energy conscious management at urban level (organic management of mobility, energy production sites, energy transport network, energy consumption sites, water, waste, etc.). Additionally, each city is in direct connection with its surroundings and beyond that embedded into superposed energy systems at larger levels (e.g. continental). These interconnections provide a spectrum of renewable energy sources from other regions, but might also act as a sink for surplus energy from the city.
Within this scenario, the general objective of this sub-programme is to develop the approaches, methodologies, technologies and pilot cases in order to optimize energy metabolism of cities toward low impact urban districts integrating all accessible sources of renewable energy and providing flexible balancing potentials, by means of an energy conscious operation & management fed by data networks spread at urban level.

This study is focussed on the main research lines of the Urban Energy Networks as a Sub-Programme of the European Joint Programme on Smart Cities (http://www.eera-set.eu/index.php?index=30). The starting off of the Smart Cities Joint Programme was held in September 2010. The research framework of the programme has been shaped throughout a series of further workshops from December 2010 till September 2011. The entire Joint programme is structured in 4 sub-programmes with a clear focus on energy efficiency and integration of renewable energy sources within urban areas. The main objective is the development of scientific tools and methods that will enable an intelligent design, planning and operation of the energy system of an entire city in the near future. An integrated approach will be adopted for the planned research activities in order to capture the interfaces between all the relevant elements of the energy system, such as thermal and electric energy networks, buildings, energy supply technologies and the end-user. At the moment includes activities of about 200 European Researchers from 20 European Countries.

The research activities of the *Urban Energy Networks* Programme will mainly focus on three main tasks:

1) *Smart Energy Districts* - it aims at developing suitable models for optimal management of low impact "Smart Energy Districts" (a settlement of different utilities such as private and public residential buildings, private and public office buildings, schools, hospitals, shopping centres, organized as a single user); solutions for a smart coupling of energy (both electrical and thermal) production, storage and consumption will be investigated and developed; mobility at district level will be also analysed in terms of energy consumption patterns. Such model includes the ability to instance a cohort of bidirectional thermal building model in order to capture with a reasonable accuracy the power demand and the main effect of potential refurbishment.

2) *Urban network integration* - it aims at studying and developing opportunities related to the implementation of data acquisition systems at urban level (multi-information sensors networks), connected to data transmission, storage, elaboration and analysis; this structure will be synthesized through an integrated ICT multifunctional platform for network integration coupled with district GIS; this platform will feed an integrated management system to optimize the balance between energy offer and demand also considering different forms of energy (e.g. electricity, fuel, heat) and taking into account end user expectations and behaviour.

3) *Human factors*: *the citizen-city interaction* - it aims at deepening the knowledge about human factors influencing energy uses and at developing "human oriented technologies" based on citizen needs and expectation for the improvement the quality of life oriented to low energy impacts.

The milestones of the *Urban Energy Networks* programme may be synthesized as follow:

- Development of a methodological approach for the integration of energy networks at urban level.
- Developments of innovative solutions to optimize the link between energy offer, distribution, storage and demand (both electrical and thermal energy) in smart urban networks, taking into account the convertibility (e.g. heat pumps) and coupling (e.g. cogeneration) between different energy forms and promoting energy demand response.
- Development of multifunctional ICT platforms and integrated logics for electrical and thermal energy management in smart urban networks taking in account the physical constraint specific to energy network (electrical, thermal) so that quality of energy delivered to customer is provided in a resilient way.
- Ambient intelligence solutions to take into account citizen needs and expectation in low impact cities.
- Pilot experiments related to smart urban networks.

Oral Presentation

LOW-COST SENSOR NETWORKS FOR URBAN AIR-QUALITY MONITORING APPLICATIONS

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Abstract
Atmospheric composition within urban areas has a direct effect on the air quality of an environment in which a large majority of people live and work. Atmospheric pollutants including ozone (O_3), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and particulate matter (PM) can have a significant effect on human health. As such, it is important to determine the potential exposure of individuals to these atmospheric constituents and investigate the processes that lead to the degradation of air quality within the urban environment.

Air quality within urban areas is highly heterogeneous in both time and space and thus characterising air pollution effectively in such environments may be complex. Whilst modelled pollutant levels on the local scale often suggest high degrees of spatial and temporal variability, relatively sparse fixed site automated urban networks only provide low spatial resolution data that do not appear adequate in detecting such small scale variability.

Previous studies have demonstrated that networks of low cost sensors which utilise a variety of measurment techniques, including electrochemical can be used to measure concentrations of atmospheric species including CO, NO and NO_2 in addition to meteorological parameters (temperature and relative humidity) within urban areas [1]. Such low cost sensors as well as others used to measure pollutants such as PM are becoming increasingly readily available for inclusion in dense monitoring networks.

Equipped with GPS and GPRS to determine position and transmit data respectively, these networks have the potential to provide valuable insights into pollutant variability inherent on the local or micro-scale and improve air pollution characterisation.

This paper presents results obtained from two sensor network deployments that provide high spatial and temporal (ranging from 2 to 20 s) resolution observations transmitted in near real time. The first of these includes measurements of CO, NO, $NO_{2,}$ temperature and humidity obtained from a 46 sensor nodes located in and around Cambridge. The second, currently deployed (40 nodes) at London's Heathrow Airport, provides additional observations of O_3,

SO_2, VOCs, CO_2 as well as size-speciated particulate matter (0.38 to 17.4 µm), wind speed and direction.
For the Cambridge deployment we show how the use of a network permits discrimination between near-field and far field emissions, and compare network results with model output simulated using the atmospheric dispersion model ADMS-Urban.

Early results from the LHR deployment reveal many features of the emission characteristics of a major airport, showing source attribution associated with different operational modes, landside and airside activities, and regional pollution episodes influenced by macro meteorology. Such results demonstrate the value of such networks in characterising air quality, emissions and validating air quality models on local scales.

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Oral Presentation

ENABLING HIGH RESOLUTION URBAN POLLUTION MONITORING THROUGH MOBILE SENSOR NETWORKS

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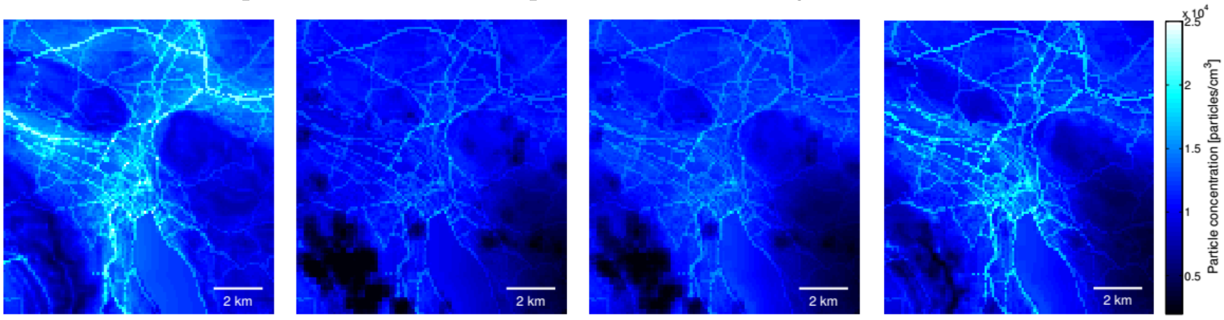
Abstract
With more than half of the world population currently living in urban settlements [1] and environmental related causes ranking among top mortality risks in both low to middle income countries and high income countries [2], there is a clear need for a better understanding of air pollution inside cities.
Wireless sensor networks (WSNs) hold significant promise to deliver the quantities of data necessary for both calibration and validation of physics-based models, and the possibility to refine the resolution of statistical models.

Figure 1. OpenSense sensor nodes on top of t-l bus in Lausanne (left) and VBZ streetcar in Zürich (right)

Within the Nano-Tera OpenSense project[1], mobile WSNs for monitoring different air quality parameters were deployed in the cities of Lausanne and Zürich. The motivation for using mobility stems mainly from economical reasoning. Mobility permits the coverage of a larger area for a given number of nodes, which means a reduction in both equipment and running costs. The backbone of the deployments consists of sensor nodes anchored to public transport vehicles: 10 buses in Lausanne and 10 streetcars in Zürich (Fig. 1). OpenSense nodes measure O_3, CO, CO_2, NO_2, particulate matter, temperature and humidity.



(a) Winter (January–March). (b) Spring (April–June). (c) Summer (July–September). (d) Fall (October–December).

Figure 2. Seasonal UFP pollution maps with a spatial resolution of 100m x 100m for Zürich, based on data collected by mobile sensor nodes throughout a year

Beyond the acquisition of large amounts of air quality data, algorithms have been developed and validated during OpenSense for achieving automatic sensor calibration, sensor fault detection, and for providing measurement accuracy bounds [3]. Based on the OpenSense data

[1] Nano-Tera OpenSense project webpage: http://www.nano-tera.ch/projects/401.php

land-use regression models have been developed for creating high spatial resolution maps of ultrafine particle pollution [4] (Fig. 2).
An important issue for obtaining accurate and spatially highly resolved air pollution data is the tradeoff between high cost of accurate air pollution monitoring sensors and the number of such devices required for monitoring a given geographical area. Figure 3 depicts this tradeoff and classifies the various techniques for gathering data. OpenSense2[2], the current follow up to the original project, envisages obtaining and using data gathered via all outlined methods.

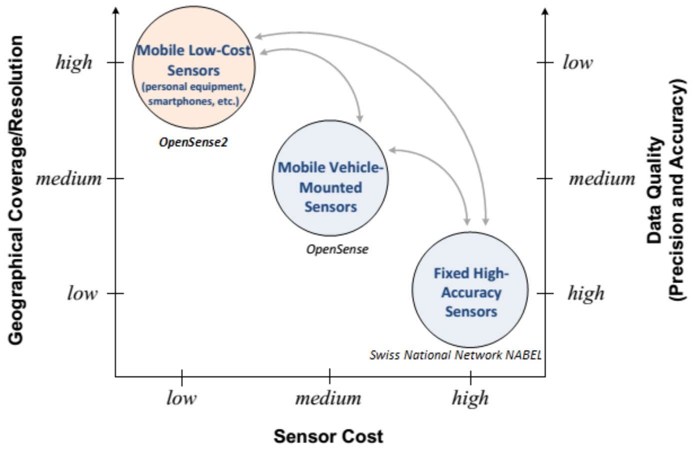


Figure 3. Sensing tradeoff for a given budget.

OpenSense2 joins together 8 Swiss laboratories with complementary expertise to achieve high resolution air pollution maps by a crowdsourcing approach. In addition to the authors whose expertise lies mainly in distributed intelligent systems, the other partners are experts in air pollution monitoring and air quality modeling (Lukas Emmenegger – Laboratory for Air Pollution/Environmental Technology, EMPA, Duebendorf), sensor data management (Karl Aberer – Distributed Information Systems Laboratory, EFFL, Lausanne), embedded sensor networks for environmental monitoring (Lothar Thiele – Computer Engineering and Networks Laboratory, ETHZ, Zurich), adaptive information acquiring systems (Andreas Krause – Learning and Adaptive Systems Group, ETHZ, Zurich), qualitative and model-based reasoning for incentive-based crowdsourcing (Boi Faltings – Artificial Intelligence Laboratory, EPFL, Lausanne), and public health studies (Michael Riediker – University Institute for Work and Health, UNIL/UNIGE, Lausanne, and Murielle Bochud – University Institute of Social and Preventive Medicine, CHUV, Lausanne).
This consortium plans to leverage the experiences of the original OpenSense project and to extend it in order to achieve air pollution maps for the cities of Zürich and Lausanne at resolutions in the order of 5 to 10 meters and to explore the human health consequences of the long-term exposure to the targeted air pollutants.

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Oral Presentation

PARTICIPATORY AIR QUALITY SENSING

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Abstract
Particulate air pollution is a mixture of particles that vary in number, size, shape, surface area, chemical composition, solubility and origin. Particulate matter in the urban air is introduced by primary emissions from combustion sources in transportation, industries and power generation, and by secondary formation through atmospheric photochemical reactions and conversion processes. The dynamics in space and time of particulate air pollution induce important pollutant specific differences between urban micro-environments. The exposure of citizens to air pollution in urban environments is strongly linked to the spatio-temporal variability of the pollutant concentrations and micro-spatial hotspot variation across suburbs. The spatial characterization of air pollution is therefore a valuable information for urban planners and policy makers, but also for residents in planning their activities. The core of this talk will highlight methodologies and recent developments for spatial air quality monitoring in urban environments, especially focusing on black carbon.

We will use the following framework (Fig. 1) to describe spatial air quality monitoring projects. The starting point is the definition of the research questions by science, community or policy (or a combination of these). An experimental set-up is designed to gain information and to address the research questions. At the interplay between sensors, participation and monitoring methods choices have to be made to obtain an optimal set-up. What data collection methods are most suitable to obtain representative information?; which sensors are most suitable given the data quality requirements?; are communities involved and willing to participate in the data collection?

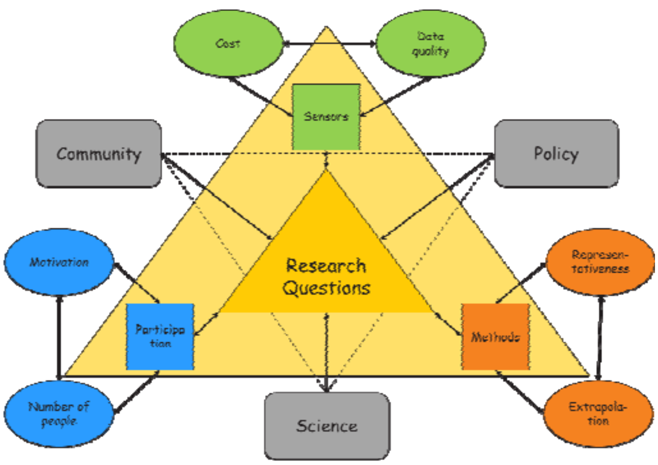

Figure 1. Conceptual framework to characterize participatory urban air quality monitoring studies.

Three different monitoring projects are discussed in this presentation: (1) a targeted and highly coordinated mobile monitoring campaign to map black carbon concentrations in urban environments, (2) a mobile monitoring campaign to map black carbon from participatory monitoring with city guards, and (3) a participatory sensing campaign by citizens using low-cost gas sensors and a calibration model to assess black carbon concentrations in four European cities.

Results from the first two projects indicate that mobile monitoring is effective in mapping the micro-spatial variation in pollutant concentrations in urban environments. However, monitoring and data processing methods are needed for quality assurance of the final maps. Repeated measurements, for example, are shown to be essential for mapping purposes. An overview from the practical set-up of a monitoring campaign up to the interactive visualization of the final result will be shown.

The final project is a community-based sensing project to collect environmental data and to use information extraction algorithms to share information to the users and the broader community. In this project, a sensor box has been developed using low-cost gas sensors as part of an integrated sensing platform. The sensor boxes were subject to a calibration procedure to estimate the black carbon concentration from gas concentrations (CO, NO_x, O_3 and VOC), and results showed a good performance in urban conditions in a stationary set-up. The mobile use of the sensor box is more challenging. Results from case studies in four European cities are presented, ranging from the recruitment strategies and data collection by citizens over the data processing to the visualization of the monitoring results.

Invited Talk

CHEMICAL SENSORS FOR THE DETECTION AND QUANTIFICATION OF INDOOR AIR POLLUTANTS

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Abstract

During the last decade, the increase of the awareness of the importance of indoor air quality and its potential impact on human health has stimulated interests in many volatile organic compounds (VOC) present in homes and in public area. Due to the large number and variety of toxic pollutants and the lack of a universal detection system, numerous methods and techniques have been proposed. However, most of the available techniques have several drawbacks in terms of the required high sensitivity and/or selectivity, and/or fast sampling time. Moreover, when these requirements are met, the resulting price is often prohibitive. Therefore, the development of a versatile sensor which can be easily adapted to the detection of a wide range of pollutants is an important and significant challenge.

In the present work, we will describe the strategies aimed at elaborating a versatile system able to trap and detect selectively a broad range of pollutants at low concentrations. These strategies are based on the use of nanoporous matrices acting as sponges and doped with various specific probe-molecules able to react selectively with the targeted pollutants. These strategies are implemented with a miniaturized detection system allowing the rapid detection of the pollutants either via absorption and/or fluorescence measurements.

Two examples of applications will be discussed. The first one concerns the selective detection of formaldehyde (CH_2O, 5ppb-1ppm, 15 min), a ubiquitous and carcinogenic air contaminant responsible for significant indoor pollution because of its numerous emission sources (plywood, isolation foam, adhesive resins, cosmetic, cigarette smoke, etc.). CH_2O concentration can vary from a few ppb to more than 100 ppb in homes [1]. As most of humans spent 80 to 85 % of their time indoor, the Agency for Toxic Substance and Disease Registry (ATSDR) recommends, for a chronic exposure during a whole life, a formaldehyde concentration as low as 10 $\mu g/m^3$ or 8 ppb.

The second application concerns the detection of nitrogen trichloride (NCl_3, 5-200 ppb, 20 min), a toxic pollutant present at ppb levels in the atmosphere of indoor swimming pools. NCl_3 is generated from the reaction of Cl_2, used as disinfectant to minimize the risk to users from microbial contaminants, with nitrogen compounds generated by human activities (saliva, sweat, urine, squams, …). At ppb levels, NCl_3 can provoke significant eye and respiratory irritations in swimmers and pool-attendants [2] and epidemiologic studies have recently shown that it could induce asthma, especially in children [3].

Both sensors are nanoporous and transparent materials, produced via the sol-gel process and doped with specific probe-molecules able to react with the targeted analytes (Fig.1). When these materials are exposed to the pollutants, the reaction induces a colour change whose intensity is proportional to the analyte concentration.

Invited Talk

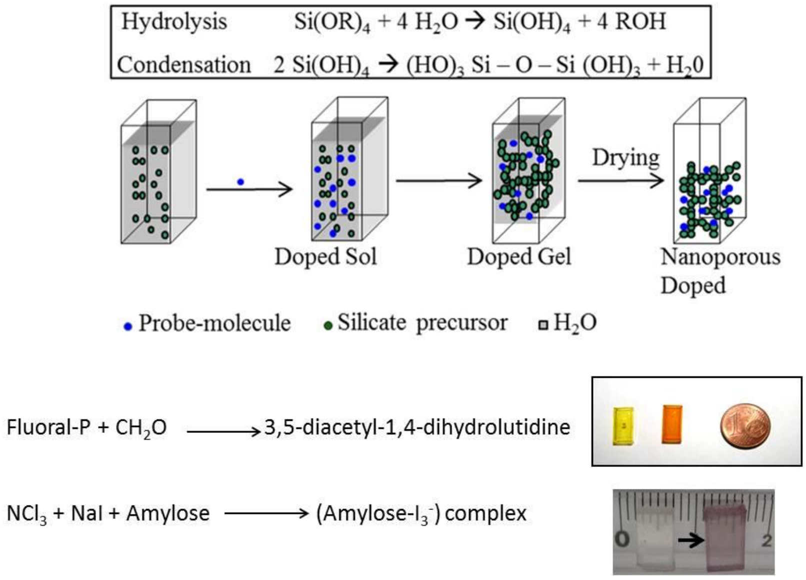

Figure 1. Schematic representation of the synthesis of nanoporous materials via the sol-gel process with silicon precursors. With Fluoral-P (enaminone) and NaI+Amylose as probes molecules, colorimetric sensors are produced for the detection of CH_2O and NCl_3, respectively.

We will show the technology transfer to a CEA-CNRS spin-off, ETHERA, and the campaigns of measurements on site the for sensors validation preceding their commercialisation.

Figure 2. ETHERA sensors. left: Profil'Air reader unit and badge for the detection of CH_2O. right: Trichlor'Air exposure and reader units for the detection of nitrogen trichloride. In both cases, the nanoporous sensor placed in a badge is inserted in the exposure unit and exposed to a flow of the atmosphere to be analysed during 15-20 min. The colour change is read with the reader unit and transformed into the pollutant concentration.

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COST Action TD1105 *EuNetAir*
2nd International Workshop *EuNetAir*, Brindisi (Italy), 25-26 March 2014

Oral Presentation

SELECTIVE DETECTION OF INDOOR VOCS USING A VIRTUAL GAS SENSOR ARRAY

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Abstract

In order to assess indoor air quality quickly and cost-effectively, an approach using metal oxide semiconductor (MOS) gas sensors was followed. A possible application for this is room ventilation optimized for health and energy efficiency. A challenge of this scenario is the very low concentration of target gases (down to low ppb levels [1]) against a background of much higher concentration. This requires both high sensitivity as well as high selectivity to the target gases. The focus in this work was on benzene, formaldehyde and naphthalene, as an interferent background gas ethanol was used.

It was shown that the MOS sensors can detect and discriminate low levels of hazardous VOCs using temperature cycled operation (TCO) of the sensors [2]. With this operating mode of the gas sensors, the temperature of the gas sensitive layer is set to several levels in order to use different gas sensing characteristics at the different temperatures as well as temperature transitions.

The TCO of three different sensor types (Type 1000, 2000 and 5000; UST, Germany) were optimized to achieve maximum sensing performance at a short temperature cycle length. The obtained cycles run for 180 s, which is sufficiently short for indoor ventilation control.

The sensors were characterized and tested in the lab using two concentrations (guideline concentration and tenfold guideline concentration) of each target gas and three background ethanol concentrations as well as two different relative humidities.

For signal analysis, Linear Discriminant Analysis (LDA) was used. With this pattern recognition and group classification method, the different gases could be detected and identified by analyzing the sensor signals. Features were extracted from several segments of each cycle (Figure 1) and an LDA algorithm was applied to the generated datasets.

One LDA result where the complete dataset of a measurement (all gas concentrations for target gases, interferent and humidity) was analyzed is shown in Figure 2. The different gases are all identified into separate groups, with little overlap. Even the small target gas concentrations can be separated from the background. The results can be improved significantly if the ethanol concentration or the humidity is known and an optimized LDA calculation is performed for this scenario.

Furthermore, the sensors were implemented into stand-alone sensor systems, designed for field tests of the sensors and the data processing. These systems were characterized in the lab as well with the same measurement parameters. One result, corresponding to the one shown in Figure 1, is illustrated in Figure 3.

The discrimination of the different gases is reduced dramatically compared to the measurements of the sensors alone. The small concentrations of every target gas can hardly be discriminated from the background, for the high concentration the separation is still working for formaldehyde and naphthalene.

As the reason for this, gas emissions of the systems themselves (plastic housing and PCB) were identified and quantified using GC/MS analysis.

This problem of gas emissions of the system materials must be addressed in future gas IAQ gas sensor system designs.

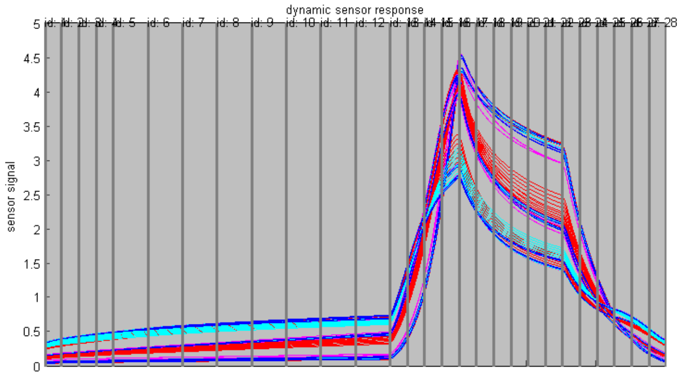

Figure 1: Plot of the signal patterns of every temperature cycle of the MOS gas sensor during a measurement. The different segments for LDA feature extreaction are indicated

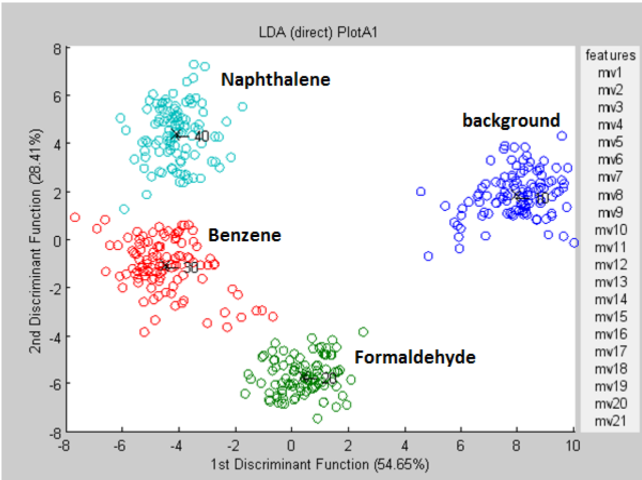

Figure 2: LDA result of a single sensor in a sensor lab test with the three ethanol backgrounds combined classified as one group

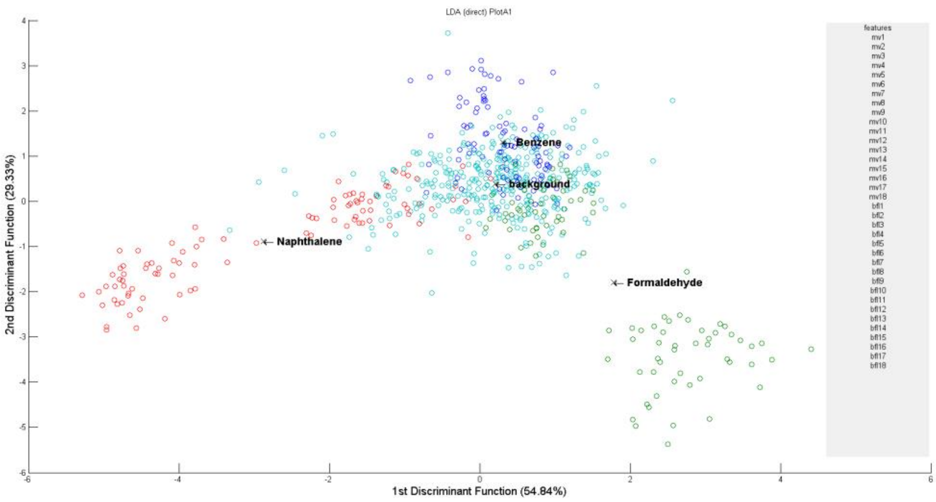

Figure 3: Same measurement as Figure 1 but with a field test sensor system

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Oral Presentation

INDOOR ENVIRONMENT AND HEALTH IN ELDERLY CARE CENTERS: THE GERIA PROJECT

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Abstract

Introduction

According to the United Nations estimates, the total number of people aged 65 years and older was 506 million in 2008 and is anticipated to double to 1.3 billion by 2040, accounting for the 14 percent of total global population. This trend explains the increasing demand of long-term care services [1] such as elderly care centers (ECC). Indoor air pollutants may have special significance for elderly, even at low concentrations due to long exposure periods. Consistent evidences from both epidemiological and experimental studies have demonstrated that short- and long-term exposure to particulate matter (PM), in particular to the finest particles (i.e. airborne PM with aerodynamic diameter less than 2.5µm, $PM_{2.5}$), is associated with cardiovascular morbidity and mortality [2]. Other studies associated indoor air pollution with cardiovascular effects [3], however, little is known about the effects of improving indoor air quality on cardiovascular health. Also, aging is associated with a decline in immune defenses and respiratory function, and predisposition to respiratory infections [4]. This paper presents results which have been produced within the GERIA ongoing project 'Geriatric study in Portugal on Health Effects of Air Quality in Elderly Care Centers', by measuring and characterizing indoor air quality (IAQ) and thermal comfort (TC) in 22 ECC in Porto, Portugal. The aim of the study was to evaluate 1) the IAQ and TC in a representative sample of ECC in Porto as compared with international standards, 2) to study the variability among different spaces within single ECC, 3) how buildings characteristics may affect the extent of indoor air pollution or thermal regulation, and 4) explore the impact of IAQ variables on elderly respiratory health.

Methodologies

Within the 1st phase of GERIA project, and based on the *Portuguese Social Chart*, 53 ECC - 33 from Lisbon and 20 from Porto - were randomly selected. From September 2012 to April 2013, the BOLD (Burden of Obstructive Lung Disease) [5] questionnaire was applied by an interviewer to the elderly who gave their informed consent and were able to participate. All the participants should had ≥ 65 years old and live in the ECC for more than two weeks. The results in this paper correspond to the pilot study of a population of 143 elderly interviewed randomly from 22 ECC in the city of Porto. Also, indoor environmental parameters were measured twice, during winter and summer, in 141 ECC rooms within dining rooms, drawing rooms, medical offices and bedrooms. These areas were assessed for IAQ chemical (CO_2, CO, Formaldehyde, TVOC, PM_{10}, $PM_{2.5}$) and biological contaminants (total bacteria and fungi). TC parameters were measured following ISO 7730:2005 (PMV and PPD indexes). A walk-through building questionnaire was performed prior the monitoring and outdoor samples were also collected for comparison. Classical statistical methods were used to estimate means, medians and frequencies (percentages) in order to obtain insight into the ECC characteristics and environmental monitoring results within and between buildings. The variables were tested for normality with Shapiro-Wilk test. Mann-Whitney *(U)* test and Kruskal-Wallis *(H)* for independent samples were conducted for seasonal effects assessment, indoor/outdoor and within buildings location differences. A 0.05 level of significance was used for all analyses. All data were analyzed using IBM SPSS 21.0.

Results and Preliminary Conclusions

The overall $PM_{2.5}$ mean concentration of the 22 ECC was above national (25 µg/m^3) and international reference levels (35 µg/m^3) in both seasons. These findings showed as these parameters are critical for air quality and could influence on human health. Other recent study [6] also found, high levels of $PM_{2.5}$ in similar indoor environments, and the link with lung function and respiratory diseases such as COPD [7] has been quite demonstrated. Although all the other indoor air pollutants were within the reference levels peak values of PM_{10}, TVOC, CO_2, bacteria and fungi exceeded the reference levels, compromising indoor air comfort and worsening the already existent respiratory chronic diseases. TVOC, Bacteria, CO and CO_2 showed significantly higher indoor levels compared to outdoor, in both seasons. Indoor PM_{10}, TVOC, Bacteria and CO_2 present significant differences between seasons ($p < 0.01$). TVOC, bacteria and CO_2 show significant variation between ECC rooms ($p < 0.01$) and 4% of fungi samples were positive for pathogenic Aspergillus species. The winter PMV index is between the ‘slightly cool’ (-1) and ‘cool’ (-2) points in the thermal sensation scale, which may potentiate respiratory tract infections. PPD and PMV indexes show significant differences by room and by season ($p < 0.01$). The building variables ‘Insulation’, ‘Heating Ventilation’ and ‘Windows frames’ were significantly associated to chemical, biological and TC parameters. ‘Bacteria’, ‘Fungi’, ‘Temperature’, Relative Humidity’, and ‘PPD index’ are the mostly affected by building characteristics. In elderly respondents, breathlessness (27.5%) and cough (23.1%) were the major respiratory symptoms, and allergic rhinitis (21.7%) the main self-reported illness. Heart troubles were reported by 36.6% residents. Symptoms of wheezing (10.5%) in the last 12 months and asthma diagnosis (8.4%) were more common in females, as opposed to symptoms breathlessness (4.9%) and sputum (3.5%), more frequent in males. Smoking habits, both past and present, were more frequent in men (11.9%).

Our study suggested that attention is needed to $PM_{2.5}$ particle fraction, as well as, peak concentrations and fungi species that might compromised IAQ comfort. To prevent low indoor temperatures and discomfort, especially on winter season, simple measures could provide health benefits to ECC residents and workers, such as insulating ceilings, walls, and windows, maintaining natural and passive ventilation, solutions that are common in Portugal due to the advantage of the country’s generally mild weather. Investigations are still needed to better understand the links between indoor air pollution and respiratory health impairment in elderly. In this sense, logistic regression analysis is ongoing, thus focusing on the impact of IAQ and respiratory health symptoms on ECCs residents.

Acknowledgement

Our current research is supported by GERIA Project (www.geria.webnode.com): PTDC/SAU-SAP/116563/2010 and a PhD Grant (SFRH/BD/72399/2010) from Foundation for Science and Technology (Fundação para a Ciência e Tecnologia - FCT).

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Invited Talk

INDOOR AIR QUALITY ASSESSMENT: TOWARDS A BETTER PROTECTION OF PEOPLE

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The effects of air pollution on health result from a chain of events, ranging from the emission of pollutants, through transport, dispersion, transformation, until the contact and absorption by humans. For exposure assessment, in addition to include the outdoor air quality, it is essential to consider indoor spaces, where people living in urban areas spend approximately 80-90% of their time, rising to 95% for more vulnerable groups, such as children and the elderly [1, 2]. Additionally, the changes in the strategies of buildings construction, particularly with the introduction of new materials and greater isolation, have led to a decrease in air exchange rates with potential effects in the concentration of pollutants.

Indoor air quality problems are consequence of the combination of multiple factors, including indoor air pollution sources, problematic levels of ambient air quality and inadequate ventilation related with energy saving strategies or occupants behaviour. In order to overcome the lack of information regarding indoor air quality in Portuguese homes the Portuguese Society of Allergology and Clinical Immunology (SPAIC) promoted a study to characterise a significant number of homes at 5 regions of mainland Portugal. From December 2007 until July 2008 samples of indoor air were collected from the master bedroom and kitchen of 557 homes distributed throughout mainland Portugal [3, 4]. The measurements were performed by IDAD in cooperation with SPAIC.

Measurements of different parameters were performed, namely carbon dioxide (CO_2), carbon monoxide (CO), particulate matter with dimension less than 10µm (PM10), formaldehyde (HCHO), volatile organic compounds (VOC), ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Temperature and relative humidity were also measured to evaluate thermal comfort. Information for characterization of each home and residents health was also collected, including smoking habits and general conditions of the house.

This work demonstrates that around 60% of the houses visited had at least one measured value above the reference values. The parameters responsible for the majority of the exceedances were VOC, CO_2 and PM10 (see Table 1).

Table 1 - Indoor air quality results from 557 homes distributed through mainland Portugal.

Parameter	Unit	Measurements (nº)	Mean	Median	Minimum	Maximum	10th percentile	90th percentile
Temp.	°C	1091	21,6	21,6	11,5	29,8	17,8	25,5
HR	(%)	1110	55,1	55,8	21,0	95,5	42,6	66,0
CO_2	$mg.m^{-3}$	1110	1159	1050	633	4795	763	1658
CO	$mg.m^{-3}$	1110	1,2	1,1	<1,1	23,3	1,1	1,1
O_3	$mg.m^{-3}$	1110	0,04	0,03	<0,03	0,18	0,03	0,05
PM10	$\mu g.m^{-3}$	1111	42,2	29,2	1	934	11,9	77,8
VOC	$mg.m^{-3}$	1085	0,77	0,60	0,03	4,28	0,26	1,44
HCHO	$mg.m^{-3}$	1111	0,01	0,01	<0,01	0,25	0,01	0,02
SO_2	$mg.m^{-3}$	1110	< 0,5	< 0,5	< 0,5	< 0,5	< 0,5	< 0,5
NO_2	$mg.m^{-3}$	1110	0,2	0,2	<0,2	2,5	0,2	0,2

The results were compared with indicative reference values specified for indoor air quality, ambient air quality legislation, as well as other references [5, 6, 7]. For the VOC measurements about 50% of the results were higher than 0,6 mg.m^{-3}, a protection threshold established in Portuguese indoor air quality legislation [5]. Moreover, 94% of the VOC measurements were above 0,2 mg.m^{-3} considered by some authors as a level of comfort were it is not expected to have odours, irritation or discomfort [7]. For carbon dioxide it was found that only 7,6% of the measurements exceeded the reference level of 1800 mg.m^{-3}. Regarding PM10, Portuguese legislation establishes limit values of 50 µg.m^{-3} for indoor air, as well as outdoor air [5, 6], and 40 µg.m^{-3} for ambient air on annual basis [6]. Considering as reference the limits indicated above, it was observed exceedances in 23% of the measurements (50 µg.m^{-3}) and 33% comparing with the annual limit value (40 µg.m^{-3}).

By studying the relationship between the concentrations of CO_2, PM10 and VOC it was also confirmed that CO_2 levels should be considered with precaution as an indicator of indoor air quality. In fact, it was concluded that an intervention in indoor air quality based on the concentration of CO_2 disregard possible exceedance for PM10 and VOC. About 90% of the exceedances were recorded with CO_2 levels below 1800 mg.m^{-3}, which is a level usually used to indicate insufficient air renewal.

In addition, with this work it was possible to confirm the importance of some sources with relevant contribution to indoor air quality such as tobacco smoke or fireplaces, as well as the contribution of individual strategies of ventilation. The conclusions of the work also point to the need for raising awareness about the impact of individual behaviour on indoor air quality. The use new sensing technologies for indoor air quality assessment could be seen as a valuable contribution to modify these behaviours.

This study was the first of its kind in Portugal and it can serve as a reference for developing knowledge for indoor air quality and its relation with multiple pathologies. The concentration of some pollutants in a significant number of measurements demonstrates the importance of indoor air quality exposure and its potential impact on comfort and health. The data allows the identification of opportunities for intervention and improvement of indoor air, especially in housing conditions, control of emission sources of pollutants or adoption of new ventilation strategies in dwellings.

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Invited Talk

COST ACTION ES1002 "WIRE": WEATHER INTELLIGENCE FOR RENEWABLE ENERGIES

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Abstract
Due to climate change and shrinking fossil resources, the transition increasingly renewable energy shares is unavoidable. But, as wind and solar energy is strongly dependent on highly variable weather processes, increased penetration rates will also lead to strong fluctuations in the electricity grid, which needs to be balanced. Proper and specific forecasting of "energy weather" is a key component for serving the purpose. Therefore, it is timely to scientifically address the requirements to provide the best possible specific weather information for forecasting the energy production of wind and solar power plants for the next minutes up to several days ahead.
Towards such aims, the COST action ES1002, *Weather Intelligence for Renewable Energies, WIRE* www.wire1002.ch has two main lines of activity: first, to follow the development of dedicated post-processing algorithms coupled with weather prediction models and measurement data especially remote sensing observations; and second, to investigate the difficult relationship between the highly intermittent weather dependent power production and the energy distribution towards end users. The second goal raises new challenges as it requires, from energy producers and distributors, definitions of the necessary forecast data and new technologies dedicated to the management of power plants and electricity grids. Twenty five European COST Countries and four non-COST countries, Australia, Canada, Japan, and USA, are participating to WIRE that is one of the largest Actions in the Earth System Science and Environmental Management domain.

The action comprises three Working Groups (WG) with the following objectives:

- Combining numerical weather models with suitable post-processing methods as well as real-time surface and remote sensing measurements.
- Establishing a common understanding between the relevant communities (wind and solar, meteorologists, energy engineers, grid managers) in order to optimize the technical and economic integration of these renewable energies into electricity grids and markets.
- Transferring knowledge across Europe, connecting the scientific and end user communities.

A Report on the current state of research and development related to measurement, modeling and forecasting technologies for renewable energy integration can be found at http://wire1002.ch/fileadmin/user_upload/Restricted/Current_State_Report/Current_State_Report_draft_final.pdf

Working Group 1. Modeling and post-processing
In the first phase of the project, a critical assessment of past and present research activities in different countries and of current knowledge gaps has been produced. The report highlight existing weaknesses for all components of the renewable energy forecast system. In particular, it allows evaluating the adequacy of numerical weather models coupled with dedicated power conversion modules to deliver accurate power production forecasts.

Furthermore, the potential of downscaling models towards higher spatial resolution will be analyzed in order to evaluate its impact when combined with appropriate post-processing applications.

Working Group 2. Measurements and Observations

The activity in WG2 aims to quantify the added value of the new observation techniques in further developing power forecasting models. In particular, the focus will be on how including ground-based and space-borne (satellite) remote sensing technologies will improve the quality of the production forecasts including at the post-processing level.
Recommendations will be provided to the scientific and users communities. Ground-based remote sensing systems include: weather radars, cloud radars, ceilometers, Total Sky Imagers, pyrgeometers, and combinations of these systems; Wind profilers and LIDARs for the wind speed and direction fields, or combinations of them; LIDAR and micro-wave systems for the determination of Liquid Water Content LWC (and possibly the Particle Size Distribution PSD) of the boundary layer - presently products of the model itself - which are required for improving the high resolution models.
The results of these post-processing improved forecasting systems has been evaluated through a benchmark excersise. Existing wind farm and solar energy plant locations have been selected for the evaluation of the available methodologies. Database(s) containing the validation data have been set up and appropriately formatted for direct use by the modelers' community.
http://wire1002.ch/fileadmin/user_upload/Documents/ES1002_Benchmark_announcement_v6.pdf

Working Group 3. Power Plants and Electrical Grid Management

Finally, the development of improved forecasting systems has been done in cooperation with end users in order to guarantee a good match between the scientific developments and the user s' requirements. A tentative implementation of the forecasts into the operational strategies of the power plants and electrical grid operators will be evaluated. At this point, it is required to establish a high level interdisciplinary collaboration between science and industry. Secondary specific applications such as the influence of "thermal rating" and icing for power lines at selected test sites will also be performed.

Main Events

- "State-of-the-Art" Workshop 22nd-23th March 2011 Mines ParisTech, Sofia Antipolis, France
- Remote Sensing Measurements for Renewable Energy. Workshop, 22nd-23rd May 2012. Technical University of Denmark DTU, Risoe Campus, Roskilde, Denmark. http://www.wire1002.ch/index.php?id=24
- WIRE Status Workshop. October 9th -11th 2013, OMSZ, Budapest, HU

Next Events

"Weather Intelligence for Renewable Urban Areas", Workshop, 2nd 3rd June 2014 Technical University of Denmark DTU, Risoe Campus, Roskilde, Denmark.

"Processing techniques for the detection of atmospheric constituents and the estimation and forecasting of solar irradiance from all-sky images", Workshop, 24th-25th June 2014, Patras, Greece.

Oral Presentation

The Urban Control Center: An ICT Platform for Smart Cities in Italy

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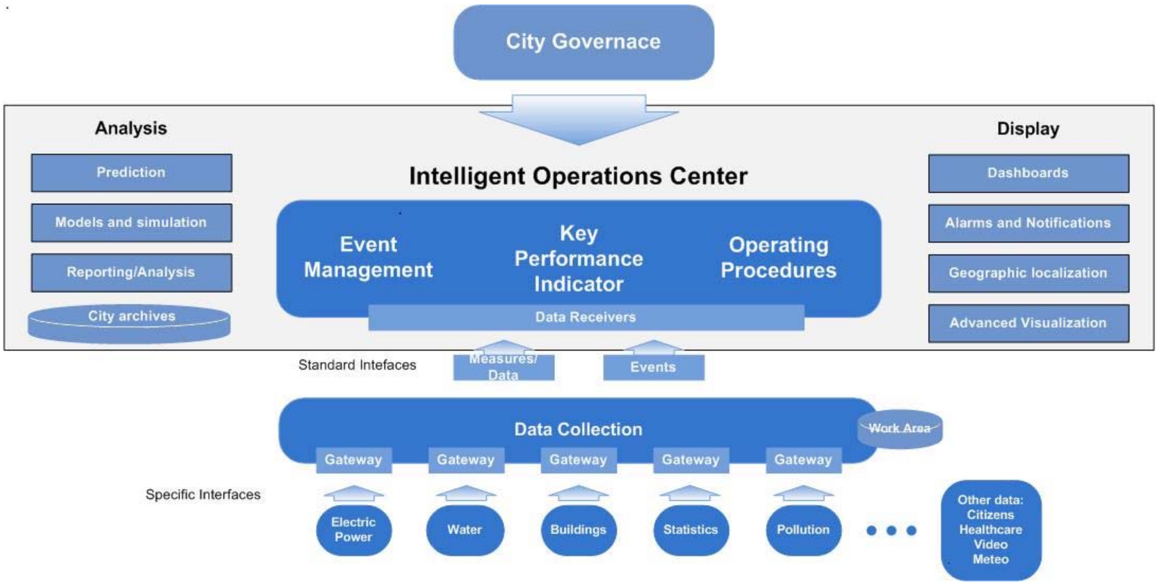
Abstract
Today many private and public organizations require efficient operational supervision and coordination. They need to get, aggregate and correlate the right information so that the entitled people can make fast, accurate decisions and track the effect of those decisions. IBM® Urban Control Center is an ICT platform that supports the decision makers in accessing and analyzing the data they need and in coordinating the appropriate city operations. At the same time citizens are asking for more transparency in the administration's decisions and so they need more awareness on how those decisions may affect their life and how they can achieve a better social behavior to improve the quality of life. The Urban Control Center goal is then to allow the Public Administration to share with citizens the planned goals and reached objectives.
IBM Urban Control Center has been selected for the research project RES NOVAE (funded by Italian Ministry of Education, Universities and Research) as the ICT platform supporting the Public Authorities in the operations and strategic decisions on energy-environment domains. The platform has the following main features:

- Automatically collect, aggregate, elaborate data from a great variety of internal sources. Data may be generated from sensors, higher level of devices or even from external ICT sources
- Integrate and analyze that data using the geo-spatial-information in the provided data showing data and events as maps, graphs, tables, or pie charts based filtered on date and time, location, and other categories that might be defined.
- Enable the P.A. to show data and elaborated indicators to citizens.
- Enable the citizen collaboration in the management of the public assets.
- Facilitate easy and timely access to information.
- Present related information in a coherent way navigating the data and events through reports and maps based on integrated geographic information system (GIS) or location plan maps. The impact of events through interactive mapping and scenario analysis can be easily derived.
- Provide a great extensibility with a rich set of integration points which enable the implementation of vertical domain solutions and, at the same time, the integration and correlation of all domain data.
- Provide support to implement workflows of operations which could enable the automatic coordination of the action to be taken by P.A. in the management of emergencies or critical issues the platform may discover or highlight.

The following picture summarizes the main functional components implemented by the IBM Urban Control Center. It can be noted how the data is gathered from different sources using different protocols. City Governance is achieved through the analysis tools, advanced display capabilities and the event and KPI management functions which elaborate the great volume and variety of data made available.



Thanks to the features mentioned above the platform helps the P.A. to get the following benefits:

- Modify or correct its strategy or day-by-day activity to meet predefined target such as PAES 2020 indicator values, citizen well-being level, energy or CO2 saving, etc.
- Optimize planned and unplanned operations by using a holistic reporting and monitoring approach.
- Integrate the knowledge in the different domains in an organization by facilitating communication and collaboration.
- Improve quality of service and reduce expense by coordinating events focusing on the integration and optimization of information within and across multiple domains in a central operations hub, in real time and over long periods.

Oral Presentation

THE URBAN CONTROL CENTER DESIGN AS A DASHBOARD AND DECISION SUPPORT SYSTEM FOR ITALIAN SMART CITIES

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Abstract

Due to increasing populations, aging infrastructures, and declining budgets, cities are encountering non-trivial long-term challenges across all their systems which are central to their operation and development. Urban performance does not only depend on the city's endowment of hard infrastructures and networks (physical capital) but it increasingly relies on the availability and quality of knowledge communication and social infrastructure (intellectual and social capital), where the latter form of capital is clearly decisive for urban progress and growth. Against this background, the concept of smart city has been recently introduced as a strategic means to encompass modern urban production factors in a common framework and highlight the growing importance of Information and Communication Technologies (ICT) and social and environmental capital in profiling cities competitiveness and sustainability [1]. In the emerging futuristic vision, cities are becoming smart not only in terms of automation of services to individual persons, buildings, traffic systems, etc., but also in terms of improved efficiency, equity, and quality of life for its citizens [2]. As a result, it emerges the need for performance assessment tools and decision support systems for the smart city [2]. These instruments are essential to capitalize the measure of the city dynamics and design performance improvement of the delivered services/products. Smart city indicator dashboards and decision aid tools help leaders, managers, and policy makers take intelligent decisions about the allocation of available resources, while supporting the communication of efforts in city performance improvement to citizens, visitors, and potential investors [3]. Figure 1 shows a scheme of the performance assessment and decision support in a smart city.

In response to the need of intelligent decision making, planning, and programming of smart cities, the paper presents the model of an innovative decision support system for efficient urban governance capable of combining the economic logics of investment with the physical structure of the territory and the enhancement of human and social capitals. The proposed tool is as part of the so-called Urban Control Center (UCC), a sort of control room of the city where the Public Administration (PA) can analyze the city dynamics and citizens can be informed on the performance of urban infrastructure and services, with a particular focus on energy efficiency and environmental sustainability concerns. The UCC provides the city manager and the PA decision makers with a series of control and decision panels for each urban sector, whose operations affect the key urban performances (e.g., residential buildings, public buildings, industry, local transportation systems, etc.).

Since the city is a complex system of systems, the proposed decision support system is based on a hierarchical model and makes use of the most modern tools of business intelligence, automation, and operational research. In particular, multi-objective decision making tools are used in order to search for optimal solutions, multi-attribute decision making tools are employed in order to provide a ranking and scoring of the determined alternatives, sensitivity analysis allows taking care of the problem uncertainty, and finally multi-participants decision making ensures the active participation of decision takers in the decision process. The proposed multi-level approach, shown in Fig. 2, allows overcoming obstacles deriving from the complexity of the context, such as conflicting objectives and requirements, fragmented decision-making, and difficult cross-optimization of sub-systems [4].

In order to highlight the advantages of the modular decision process architecture, the paper also presents the description of a specific decision-making sub-system at low level unit. In particular, the results of the optimal determination of retrofitting interventions on a given stock of public buildings is provided to demonstrate the approach successfulness in helping the smart city governance take optimal decisions towards the improvement of each urban sub-system (in this case the public buildings sub-system of the smart city).

The paper results are obtained in the framework of project *Res Novae* - PON_04a2_E/8, supported by the "*Smart Cities Communities and Social Innovation*" program of the University and Research Italian Ministry and of the research activities carried out in *Res Novae* by the Decision and Control Laboratory group of the Department of Electrical and Information Engineering of the Polytechnic of Bari, Italy.

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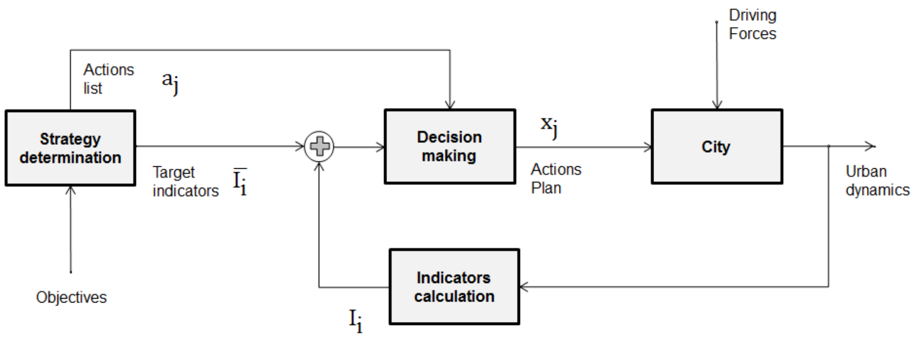

Figure 1. Performance assessment and decision support scheme in a smart city.

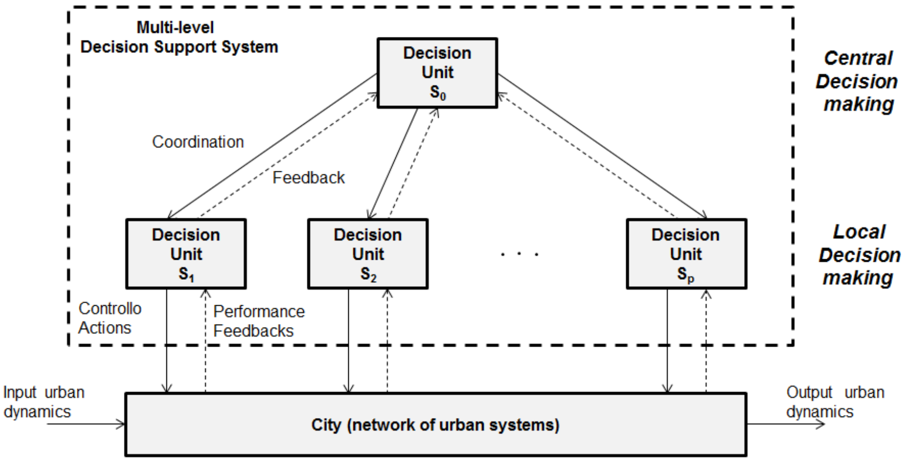

Figure 2. Decentralized multi-level decision support system for smart city governance.

Oral Presentation

DEVELOPMENT OF A PORTABLE SENSOR SYSTEM FOR AIR QUALITY MONITORING

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Abstract

Environmental monitoring is strongly required to protect the public health and save the environment from toxic contaminants and pathogens that can be released into air. Air-pollutants include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), that originate from various sources such as vehicle emissions, power plants, refineries, industrial and laboratory processes. However, current monitoring methods are costly and time-consuming, also limitations in sampling and analytical techniques exist. Clearly, a need exists for accurate, inexpensive long-term monitoring of environmental contaminants using low-cost solid-state gas sensors that are able to operate on-site and real-time. Calibrated cost-effective gas sensors are a very interesting solution for networked systems suitable to monitor air-pollutants in urban street and real scenario of smart cities with high spatial and time resolution. In ENEA, at Brindisi Research Center, a handheld gas sensor system, called *NASUS IV*, based on solid state gas sensors was designed and implemented [1-3]. This system is the last result of our researches in the area of tiny and portable system building for air quality control based on cost-effective solid state gas-sensors. The main goal of the system designed and built in our laboratory is the development of a handheld device in order to detect some air-pollutant gases such as CO, SO_2, NO_2 and H_2S in the urban areas at outdoor level, including indoor applications for chemical safety and green buildings.
NASUS IV is formed by four modules, or four PCBs: (*i*) *main module*, (*ii*) *sensor module*, (*iii*) *wireless module* and (*iv*) *power module*. The first three modules (PCBs) are packed in the same handheld case, but the power module is arranged in a separate case as shown in Figure 1.

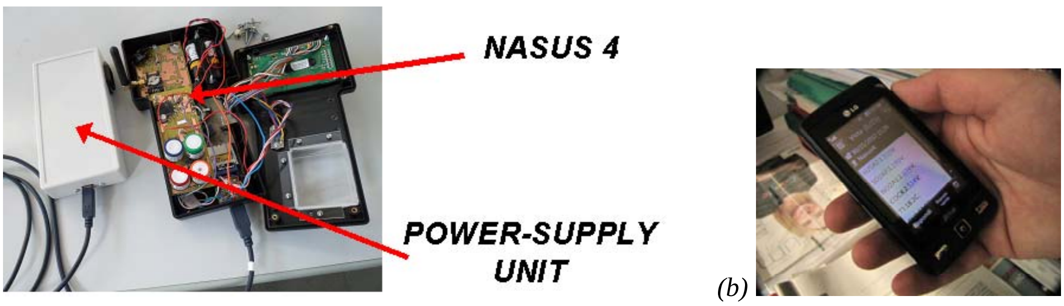
(a) (b)


Figure 1. (a) *NASUS IV* inside and power supply unit. (b) Mobile phone connected to *NASUS IV*.

The *main module* is in charge of managing the communications with the *wireless module* and with the PC via USB port, as well as, driving the local display, driving the mini-joystick (which is one of the input system, but not the only) and driving the SD-card memory. On the *sensor module* are arranged six sensors: a *temperature sensor*, a *humidity sensor* and four *electrochemical solid-state gas sensors*. The wireless module allows to control the remote device by means of commands inside a SMS sent from a mobile phone (see Figure 1b), which will get the SMS answer returning from *NASUS IV*. Furthermore, it can send *e-mails* containing any sensor data requested by the remote end-user mobile phone. The power module provides to charge a battery inside *NASUS IV*. Moreover, it performs a smart management of the available power sources (network electricity or solar energy), by giving priority to the solar one, whether possible. Currently, the sensors onboard *NASUS IV* are the electrochemical type sensors for the detection of CO, SO_2, NO_2 and H_2S provided by Alphasense Ltd (UK). We decided to test these electrochemical-type gas sensors inside our device because of their interesting features such as, for an example, low-cost, very low power consumption, small dimensions, good sensitivity and improved response to the interfering gases in real-world situations.

We performed several tests in our laboratory by directly injecting the gas inside the case (volume ca. 50 cm^3) of the *NASUS IV* in order to verify the system capabilities, before in-field testing and sensing measurements in real scenario. Some laboratory results [4] of the sensor-system for a ppb level of NO_2 (20 - 300 ppb range) detection have been measured successfully. These are very promising for real-world applications.

Typical real-world measurements performed in air quality monitoring stations are shown for CO (Figure 2) and NO_2 (Figure 3) real-time monitoring.

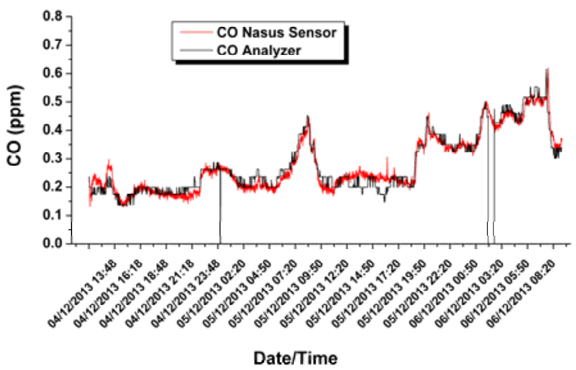


Figure 2 COCX sensor response to CO air-pollutant in *NASUS IV* system *versus* CO gas referenced analyzer by ARPA-Puglia.

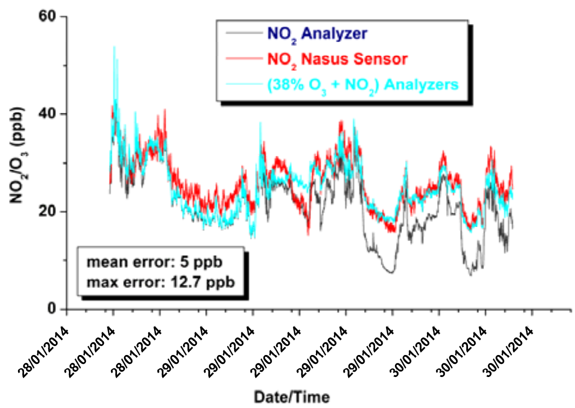


Figure 3 NO2A1 sensor response to NO_2 air-pollutant in *NASUS IV* system *versus* NO_2 gas referenced analyzer. Correction to NO_2 sensor response with O_3 referenced contribution has been estimated.

Currently, we are performing long-term experimental campaigns by *NASUS* sensor-system (Figure 5) in the real environment by the collaboration with ARPA-Puglia, the Italian public environmental agency, which is providing the availability of urban/industrial fixed air-quality stations, under *science and technology agreement* between ENEA and ARPA-Puglia, in order to compare the sensing performance of our portable sensor-system with the referenced gas analyzers (Figure 4 and Figure 6), as regulated by Air Quality Directive 2008/50/EC (*Ambient air quality and cleaner air for Europe*).

In conclusion, these preliminary results of the experimental campaign are very promising to develop a real deployment of an accurate low-cost sensors network for urban air quality monitoring. This new cost-effective sensor technology should enhance the management of the environmental emergencies in the urban areas and critical hot-spots for intelligent cities. Finally, the personal exposure of the citizens and citizen communities towards air-pollution could be measured by these innovative operated-automatically AQ sensor-systems with performing functionalities of data local storage, portability and wireless communications, including smartphone operations. However, further and deep investigations in real scenario at urban scale are planned by long-term experimental campaigns to corroborate this proposed sensing solution for challenging applications in smart cities.

Figure 4. Air Quality Monitoring Station of ARPA-Puglia, Environmental Protection Regional Agency (Bari, Italy).

Figure 5. *NASUS* sensor system integrated in box (IP65/66) for Air Quality Monitoring in sensor networks at outdoor level.

Figure 6. Air Quality Monitoring Mobile Laboratory.

Acknowledgements
The authors ENEA are indebted to JRC-Ispra, Institute for Environment and Sustainability, for fruitful cooperation in air quality sensors performance assessment.
The authors ENEA thank ARPA-Puglia for fruitful collaboration to experiment the air-quality control sensor systems in air-monitoring stations network.

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Invited Talk

AIR QUALITY IN SPANISH CITIES. FIRST STEPS IN SMART SENSORS VALIDATION

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Abstract

In Europe, the majority of the population lives in areas where air quality levels frequently exceed WHO's ambient air quality guidelines [1]. Nevertheless, concentrations of PM_{10} and $PM_{2.5}$ have been shown to decrease in the last 10 years in many areas [1,2], although there is still place for improvement.

Currently, long time series of air pollution data can only be obtained from specific stations instrumented with costly air quality monitors. This setting provides accurate data but, given the cost associated with this type of sites, the number of stations per city is limited. As a result the spatial variability within cities is hardly studied, and consequently the personal exposure to different pollutants can only be calculated with some limitations. However, the within city variability is sometimes studied by carrying out intensive sampling campaigns. Some of these studies carried out in Barcelona are summarized here [3-6].

The NO_2 concentrations have been shown to vary widely across the city, being much higher close to traffic hotspots. The NH_3 concentrations also showed spatial variations [3]. NH_3 concentrations were significantly higher at urban background than at traffic sites during summer, probably indicating the impact of emissions from biological sources, such as humans, sewage systems and garbage containers. Conversely, in winter, levels were higher at traffic sites, suggesting a contribution from vehicle emissions.

The particulate matter (PM) composition and sources influencing personal exposure of pregnant women in Barcelona was investigated [4]. To this end, indoor, outdoor and personal exposure measurements were carried out for a selection of 54 pregnant women for $PM_{2.5}$, black smoke, major and trace elements, and polycyclic aromatic hydrocarbons (PAHs) concentrations. $PM_{2.5}$ concentrations were higher for personal samples than for indoor and outdoor environments. The contribution of the PM sources found varied widely among women, especially for cigarette (from zero to up to 4 $\mu g/m^3$), train/subway (up to more than 6 $\mu g/m^3$) and cosmetics (up to more than 5 $\mu g/m^3$). These findings reveal the wide variation of exposure concentrations for women living in the same city.

Another study investigated the trace and major elements concentrations in PM_{10} and $PM_{2.5}$ at 20 sites spread in the Barcelona metropolitan area [5]. Collected samples were analyzed for elemental composition. Several differences among sites were identified: at the traffic sites Ba, Cr, Cu, Fe, Mn, Mo, Pb, Sn, Zn and Zr were found in higher concentrations (Figure 1); Br, Cl, K, and Na (sea salt origin) and Ni, V and S (shipping emissions) concentrations were higher at the coastal sites; and Zn and Pb (typically industrial tracers) concentrations were higher at sites closer to industrial facilities. These results again confirm the within-city variability for different pollutants.

A large study carried out in 40 schools in Barcelona [6] showed that average indoor and outdoor $PM_{2.5}$ concentrations recorded at the schools were significantly higher than ambient concentrations registered at a reference urban background site. Hence, this indicates the necessity of having spatially-resolved measurements to be able to assess children exposure to air pollution.

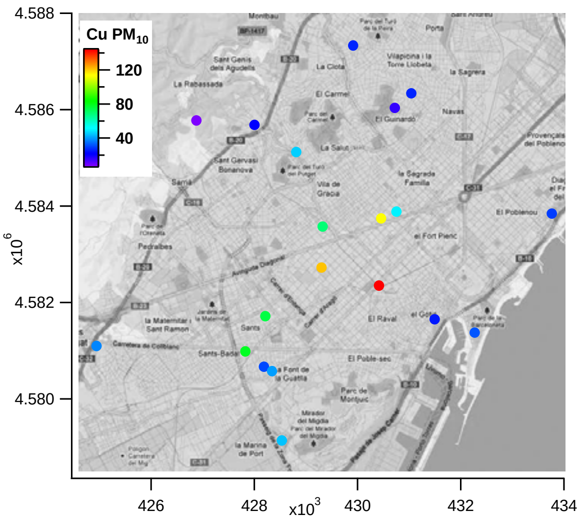

Figure 1. Average copper concentrations in PM_{10} (ng/m^3) at 20 sites in Barcelona [5].

In order to solve these limitations and progress towards a better spatially-resolved pollutants exposure, several sensors have been developed to monitor gaseous pollutant concentrations (mainly O_3, NO_2, NO, SO_2, VOCs, CO and CO_2), although research is still underway for sensors to measure PM concentrations. These sensors would enable to obtain spatially-resolved concentrations of different pollutants at a reasonable cost. Currently, most air quality sensors have been only tested under laboratory conditions, whereas real-world tests are scarcer and in some cases not as promising as for laboratory tests. Nonetheless, several past and ongoing projects are based on new sensor technologies for air quality monitoring [7].

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Oral Presentation

PARTICULATE MATTER IN DIFFERENT ATMOSPHERIC RESERVOIRS: COPENHAGEN, A HIGHLY POPULATED AREA VERSUS STATION NORD, A REMOTE HIGH ARCTIC SITE

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Introduction

Particulate matter (and especially ultrafine particles with diameters < 100 nm within the submicrometer size range) has attracted much attention in recent years as it is suspected to cause adverse health effects [1]. The human activities in major cities principally lead to the emission of submicrometer particles. Here, exposure levels can be very high, but up to now no regulations on the exposure levels of ultrafine particles are settled within EU. In remote areas as the Arctic no dominant particle sources of anthropogenic origin are observed. But during certain time periods pollution from other parts of the world reaches the Arctic (Arctic haze) leading to a contamination of the Arctic atmosphere. In the Arctic, climate effects are of major interest in view of the strong changes of the Arctic environment as there is the increase of the Arctic surface temperature and the corresponding acceleration of the melting of ice [2].

Measurement sites

Two measurement areas were used to investigate particle physical and chemical parameters in different atmospheric reservoirs. Area 1: three stations in and around the greater Copenhagen area, an urban curbside station (H. C. Andersens Boulevard), an urban background site (H.C. Ørsteds Institute) and a regional background site west of Copenhagen (RISØ peninsula). Area 2: Villum Research Station (VRS) at Station Nord (81^{o}36’N, 16^{o}40’W) in North East Greenland.

Methods

A Differential Mobility Particle Sizer (DMPS) was operated at the stations in the Copenhagen area to measure the particle number size distribution in the submicrometer size range (6 to 700 nm) for more than 10 years [3]. A Scanning Mobility Particle Sizer (SMPS) was operated at Villum Research Station (VRS) (10 to 900 nm) to measure the particle number size distribution from 2010 and ongoing.
A filterpack sampler was used at VRS to receive weekly samples of TSP and a SM200 was applied at the urban background to receive daily samples of PM2.5. Analysis of these samples for elemental and inorganic composition was done by ICP-MS and ion-chromatography. Elemental and organic carbon was analyzed on weekly samples of PM10 at VRS and on daily samples of PM2.5 at the urban background in Copenhagen received from a high volume sampler using a thermo optical method.
Based on the data, source apportionment was performed using COnstrained Physical REceptor Modelling (COPREM) in order to clarify the origin of the observed aerosol [4].

Results

Particle number concentrations were calculated for specified size regimes and are shown in Figure 1 for the Copenhagen area. As a general finding, the particle number concentrations are highest at the urban curbside for all different size regimes and decrease with distance to potential sources, meaning the lowest concentrations are found in the regional background. Particle number concentrations in all different size regimes show a decreasing trend at the urban curbside over the last nine years, which is in agreement to the development of combustion engine technology, the reduction of sulfur content in fuels and the application of after treatment technologies as e.g. diesel particle filters. Total yearly number concentrations at the curbside station decreased from about 26000 cm^{-3} in 2002, and about 21000 cm^{-3} in 2006 to about 15000 cm^{-3} in 2013.

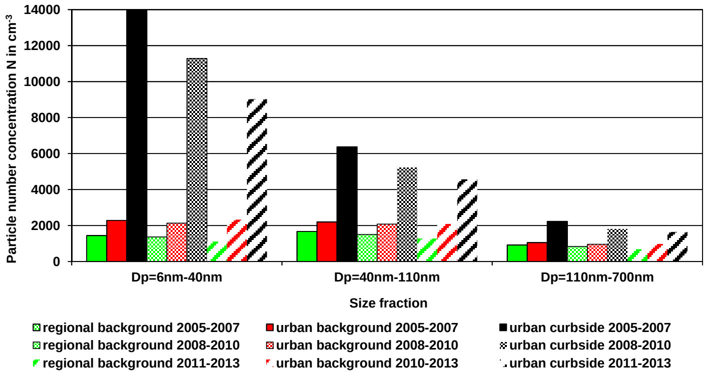

Figure 1. Averaged particle number concentrations measured for 2005 – 2007, 2008 – 2010, 2011 – 2013 in specific size regimes: Dp_{R1} = 6–40 nm, Dp_{R2} = 40–110 nm and Dp_{R3} = 110–700 nm at the different stations.

In contrast, total monthly median number concentrations at the Arctic site were between 90 and 330 cm^{-3} in 2012. A detailed view shows a clear seasonal cycle of the particle number size distribution in the Arctic indicating a persistent accumulation mode during November - February, which became more prominent from March to May representing the Arctic haze period at that site. This accumulation mode is expected to originate from long-range transported air masses. The number of particles is very small compared to urban highly populated areas or even regional background areas, but the climate effect of these particles can be significant in terms of e.g. the amount of black carbon, which is deposited on snow- and ice- covered surfaces accelerating the melting of these surfaces.
Source apportionment of urban background $PM_{2.5}$ aerosols in Denmark concluded secondary inorganic aerosols to be the most abundant (38% of PM2.5). While marine sea salt particles (8%) and secondary organic aerosols (10%) are the major natural sources, minor natural sources include primary biological aerosol particles and a crustal source. Biomass burning and coal combustion are the major anthropogenic sources accounting for 7% of $PM_{2.5}$ each, whereas traffic, oil combustion and additional anthropogenic sources are also observed.
In contrast, only 4-5 sources could adequately account for sources to TSP at the Arctic site Station Nord. Natural sources include a marine and a crustal source. Abundant anthropogenic sources are related to mining activities (Zn and Cu/Ni, respectively), and combustion of fossil fuels, which primarily originates from Siberia, Russia.

Acknowledgement

This work was financially supported by the Danish Environmental Protection Agency.

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Invited Talk

TOWARDS ZERO-POWER GAS DETECTION SYSTEMS BASED ON SINGLE NANOWIRES

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Abstract

Nanowires have emerged as potential building blocks for future sensing devices thanks to their large surface-to-volume ratio [1] and to the possibility of growing them monocrystalline and almost defect-free [2], which gives rise to controlled and reproducible properties. For the fabrication of gas sensors using, for example, metal oxide nanowires as active elements, similar paths as for the integration of metal oxide nanoparticles for this purpose have been followed: dispersion or growth of the nanowires on top of interdigitated electrodes. This has not given rise to substantial differences between both approaches, as the sensing properties in both cases arise mostly from the inter-grain or inter-nanowire contact. However we have demonstrated that the basic gas sensing response that would be obtained from using individual nanowires instead of bundles are kept and this has paved the way of working with individual objects, which allows for an increased miniaturization and low power consumption devices. It is exactly around this principle that we have worked in the development of gas sensing based on individual metal oxide nanowires.

In this work we will present the results of our research in developing gas detection systems based on individual nanowires. For this purpose we have been using single crystalline, dislocation free metal oxide nanowires (SnO_2, In_2O_3, …) with diameter in the range of 40 to 400 nm, synthesized by chemical vapor deposition (CVD) of molecular precursors [$Sn(O_tBu)_4$ for the case of SnO_2] [2] grown on ceramic substrates. The nanowires have been removed from these substrates and transferred onto different types and sized suspended microhotplates with integrated heater and interdigitated microelectrodes, some developed ad-hoc for this purpose, others from commercial origin. Advanced metallization techniques based on Focused Electron Beam Induced Assisted Deposition (FEBID) inside an SEM instrument have been carried out to fabricate the contacts to the individual nanowires [3], the resulting device being depicted in Figure 1.

Two different low-power operation modes are identified according to the heating method used to achieve the high temperature operation required for these devices. On the one hand, the independent use of the microhotplate's integrated heater to reach the operation temperature and of the interdigitated electrodes to allow the measurement of the resistance change in the presence of different gases. Typical power values to achieve the adequate operating temperature can be as low as 8 mW. This has allowed us the development of a portable gas detection system based on these devices and that can be operated with batteries, as shown in Figure 2.

On the other hand, the self-heating of the nanowires when a measuring current flows through them allows the simultaneous the heating and measuring the nanowire, dramatically reducing the power consumption by 2-3 orders of magnitude and simplyfing the practical operation of the devices. However, the required control electronics that assures the correct and stable current flow through the device becomes much more complex. Based on this approach

we have developed a portable detection system that uses a thermoelectric generator to provide the required operating power to both heat and read-out the gas sensing results [4].

In this work we will show which is the degree of maturity of both approaches in the way to develop almost zero-power gas detection systems based on individual nanowires and we will critically discuss the steps required to further improve the sensing properties and to transfer the approach for mass production.

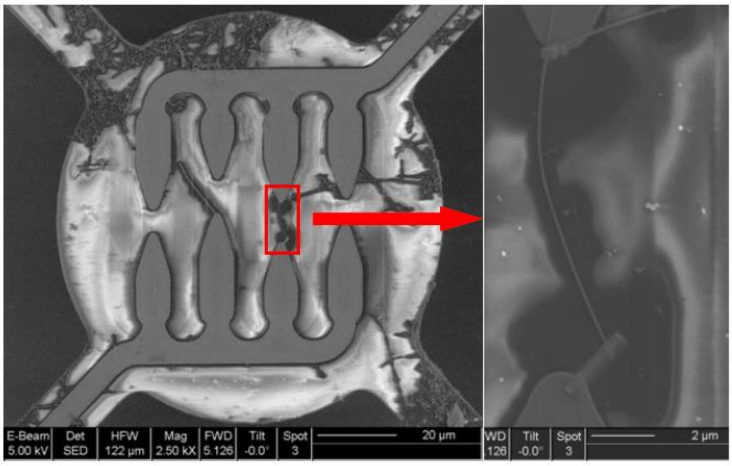

Fig. 1: Microhotplate with contacted nanowire and zoom into it.

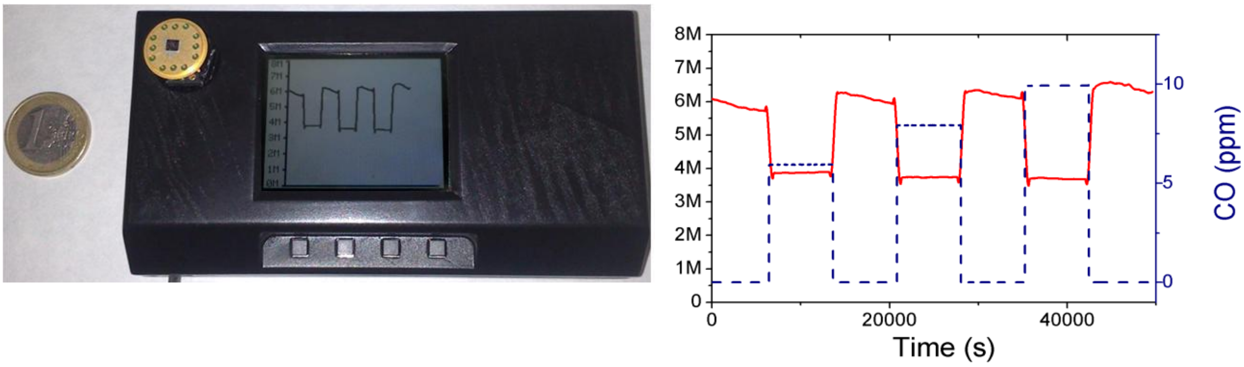

Fig. 2: (Left)Portable gas detection system based on microhotplate and individual nanowires. (Right) Gas sensing result and comparison with the gas concentration.

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Invited Talk

GAS SENSING WITH EPITAXIAL GRAPHENE ON SILICON CARBIDE: PERFORMANCE TUNING FOR AIR QUALITY CONTROL

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Graphene-based gas sensors normally show ultra-high sensitivity to certain gas molecules while suffering from poor selectivity and slow response and recovery. Several approaches based on graphene functionalization have been demonstrated to improve these issues, but most such measures result in poor reproducibility. Here we report on surface modifications of epitaxial graphene on SiC (EG) with metal and metal-oxide nanostructures, formed by highly reproducible thin film deposition techniques, and their effect on the electronic properties of the graphene and on gas interactions at the graphene surface. It is demonstrated that under the right metallization or decoration conditions the electronic properties of the surface remain those of graphene, while the surface chemistry can be modified to improve sensitivity, selectivity and speed of response toward e.g. nitrogen dioxide (NO_2) or certain toxic volatile organic compounds (VOCs). These gases are important to monitor due to their high toxicity already at parts per billion (ppb) concentrations. Sensors with extremely low detection limits, selective towards these gases, can be useful for air quality control applications.

Large area epitaxial graphene was prepared by sublimation of SiC and subsequent graphene formation on semi-insulating, Si-terminated, 4H-SiC (0001) on-axis substrates at 2000°C in argon and at a pressure of 1 bar [1]. Chemiresistor sensor devices were manufactured on the EG by deposition of Ti/Pt electrodes and subsequent mounting onto a sensor header with integrated heater and temperature sensor. The sensor response to ppb amounts of NO_2 and several toxic VOCs was evaluated from room temperature to 200°C for sensors with and without surface modification.

Reproducibility problems in graphene sensors normally originate from inhomogeneities or imperfections arising from the graphene synthesis. We have previously demonstrated that monolayer graphene is crucial for optimum gas sensitivity, related in part to the relationship between energy dispersion and the graphene layer thickness [2]. It is therefore desirable to have uniform monolayer graphene as starting material, and the talk will include a brief description on recent progress in growth of epitaxial graphene on SiC. Sensors manufactured on uniform monolayer epitaxial graphene show excellent reproducibility, as seen in Fig. 1, showing the response to 50 and 100 ppb NO_2 for three different sensors.

Surface potential mapping by scanning Kelvin probe microscopy on the graphene used in this study showed a distribution of about 90% mono and 10 % bilayer graphene, where the contrast arises from their differing work functions [3]. After deposition of very thin (0-5 nm) metal or metal-oxide nanostructures, the morphology showed the formation of grains or nanoparticles. However, surface potential mapping demonstrated that the electronic properties of the surface remain those of graphene.

The effect of decoration on the sensor response strongly depends on the choice, thickness and nanostructure of the material [4]. Decoration with Au of a certain structure gave a significantly larger and faster response to ppb concentrations of NO_2 compared to the as-grown graphene (see Fig. 2a and 2b), with a detection limit below 1 ppb (Fig. 2c), while suppressing response to CO and H_2 (Fig. 2d). In general, the sensitivity, selectivity and response time to NO_2 are significantly affected upon modifying the graphene surface by the addition of thin, nanostructured Au or Pt. It is expected that decoration with different metals or metal-oxide nanostructures will allow careful targeting of selectivity to specific molecules.

Our preliminary results indicate that decoration with TiO_2 quantum dots and nanoparticles can be used in a similar way to detect ppb concentrations of benzene and naphthalene, respectively, and that the selectivity depends on the size of the structures.

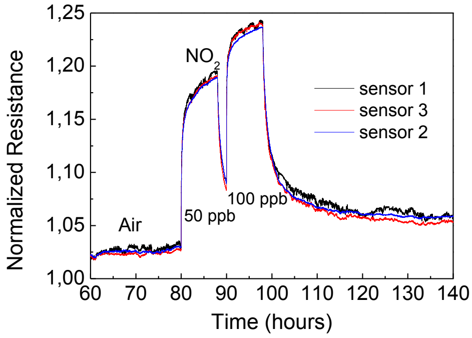

Figure 1. Reproducibility: Nearly identical response (at 100°C) to NO_2 for three different sensors manufactured on as-grown epitaxial monolayer graphene on SiC.

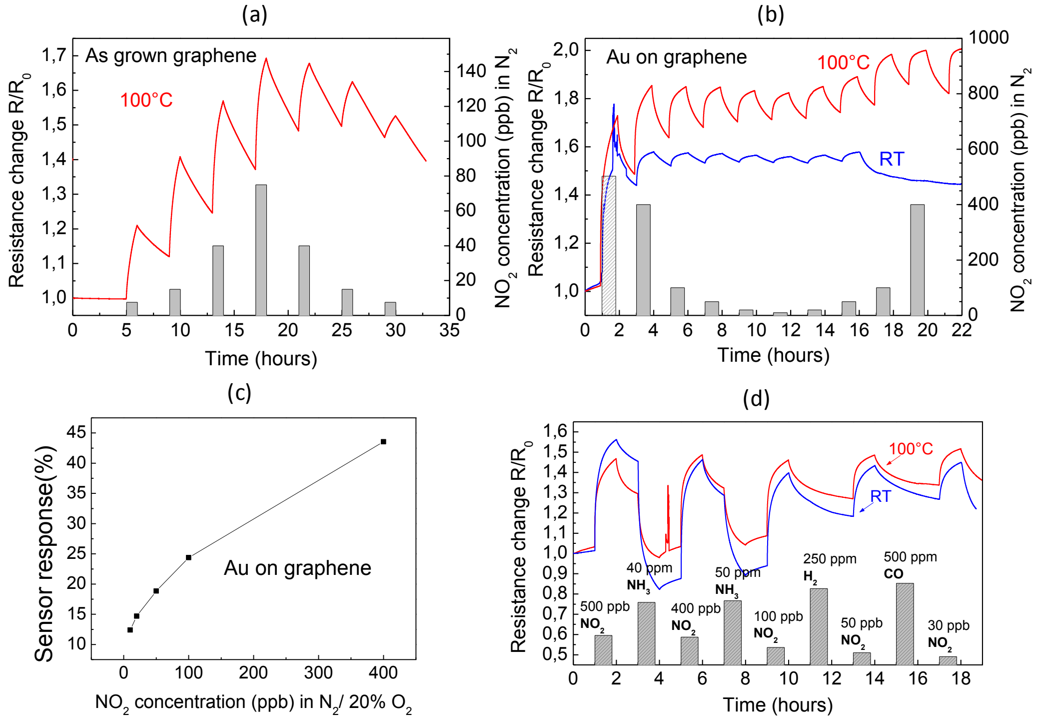

Fig. 2. Effect of Au decoration on sensor performance: Response at room temperature and 100°C to NO_2 concentrations ranging from 10 ppb to 500 ppb for as-grown graphene (a), graphene decorated with <5 nm of nanopouros Au (b) (due to small response, the signal at RT for as-grown graphene is not shown). c) Response versus NO_2 concentration after Au decoration; d) response to NO_2, NH_3, H_2, and CO for Au decorated EG.

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Invited Talk

SENSING DEVICES BASED ON METALLOPHTHALOCYANINES AND METALLOPHTHALOCYANINE/NANOCARBONS HYBRID MATERIALS: APPLICATION TO AROMATIC HYDROCARBONS DETECTION

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Objective and motivations

Volatile Organic Compounds (VOCs) are a variety of gaseous chemicals coming from biogenic processes or anthropogenic activities which exhibit hazardous effects on environment and people. If some of them can have a direct impact on health, others are involved in photochemical processes leading to the formation of secondary pollutants like ozone. Among all these compounds, Benzene, Toluene and Xylenes (BTX) have their own exposure limits defined by international health organizations, environmental agencies and Institutions (WHO, OSHA, US EPA, European Parliament and Council). These values are from few ppm for general public to 200 ppm in occupational context. In France, the recent second Environment Health National Plan reiterates the necessity to decrease the level of VOCs emission with a special focus on benzene. Thus, because of their ubiquity as well as their high toxicity, their monitoring remains full of interest and sensor development worthy of investigation.

This lecture deals with the potentialities of metallophthalocyanines and phthalocyanine/carbon nanotubes as sensitive materials of chemical sensors for BTX monitoring. The intercomparison of sensing performances has been achieved and will be discussed.

Relevance of metallophthalocyanines-based QCM sensors for BTX detection

Because of the presence of benzene rings at peripheral position of the macrocycle, metallophthalocyanines can interact with aromatic compounds through π-stacking interactions leading to gas adsorption. The involved interaction forces remaining weak, chemisorption is unlikely and Quartz Crystal Microbalance (QCM) appears as the most attractive transducers to quantify the adsorption rate as well as to develop highly sensitive sensors. Another interest of metallophthalocyanines for sensor development is the great facility to achieve thin films by several techniques of deposition.

Among these molecular materials, we have clearly established that tetra-tert-butyl metallophthalocyanines exhibit a high affinity to toluene and xylenes as compared to unsubstituted ones. To develop QCM-based sensors, thin films of tetra-tert-butyl-metallophthalocyanines including copper or zinc as central metal atom (ttb-MPc; M = Cu, Zn) have been deposited by thermal evaporation on AT-cut quartz crystals and characterized by FT-IR spectroscopy. With a resolution close to 10 ppm, a threshold of few ppm, a high level of reproducibility and stability (see Fig.1), such sensing devices working at room temperature are well-adapted to achieve the BTX monitoring in the concentration range corresponding to the guidelines and standards. Their insensitivities to CO, H_2S and NO_2 have been highlighted by experiments and point out their partial selectivity to aromatic hydrocarbons. The interaction of ozone will be also illustrated and discussed.

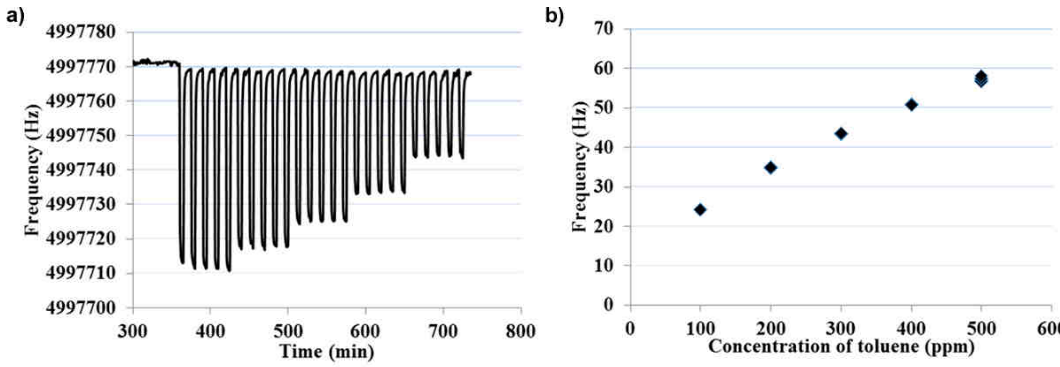

Figure 1. ttb-CuPc-based QCM sensor response toward toluene at room temperature; a) time-dependence response; b) frequency shift during 3 minutes of exposure versus toluene concentration.

Sensing properties of phthalocyanine/nanocarbons hybrid materials

The aromatic nature of metallophthalocyanines and the delocalization of π-electrons can also explain the strong interaction of this material with nanocarbonaceous matrix. Moreover, the substitution of peripheral hydrogen atoms of phthalocyanine macrocyle by tert-butyl groups improves the solubility of these compounds. As a consequence, ttb-CuPc and ttb-ZnPc can be immobilized on nanocarbons resulting in a non-covalent functionalization which can be performed into an appropriate solvent. Because of the high specific surface area of nanocarbons, an enhancement of sensor sensitivity should be obtained.
QCM-based sensors were thus realized with ttb-MPc/SWCNTs as sensitive material and compared to ttb-CuPc-based sensing devices previously described. The functionalization of carbon nanotubes was performed into chloroform to ensure a better dispersion of macrocycles and thin films were consecutively obtained by drop-casting process on AT-cut quartz crystals. Functionalized carbon nanotubes were characterized by TEM (Fig. 2), TGA and UV-vis spectroscopy: the presence of phthalocyanine molecular units at the surface of the nanocarbonaceous materials was proven. Calibration curves of QCM sensors were determined towards toluene and xylene at room temperature and pointed out the increase in sensor sensitivity as compared to ttb-CuPc (see Fig. 3) most likely due to the higher surface/volume ratio of the hybrid material.

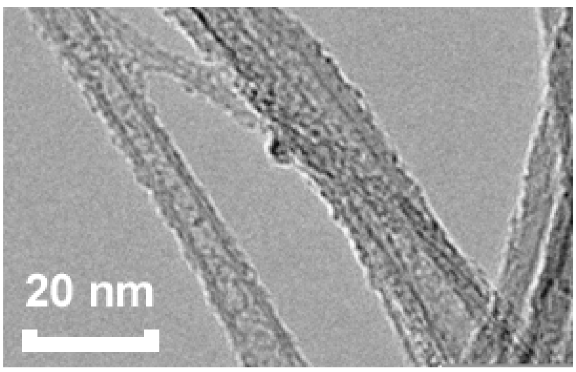

Figure 2. TEM micrograph of ttb-CuPc / CNTs hybrid material.

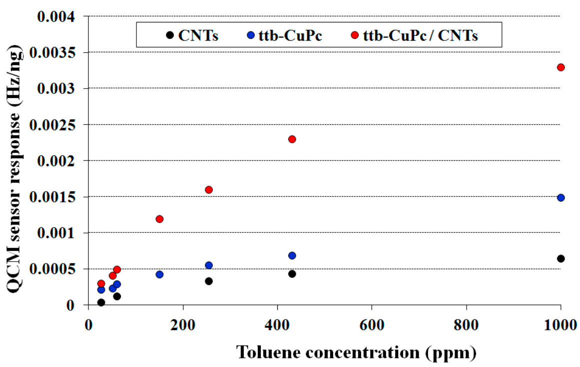

Figure 3. Comparative sensor sensitivities towards toluene for SWCNTs, ttb-CuPc and ttb-CuPc/SWCNTs thin layers at room temperature.

COST Action TD1105 *EuNetAir*
2nd International Workshop *EuNetAir*, Brindisi (Italy), 25-26 March 2014

Invited Talk

DETECTION OF LOW CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS WITH SIC-FIELD EFFECT TRANSISTORS

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Abstract
Common living environments such as homes, schools, or workplaces, where the exposure to indoor air pollutants is continuous or prolonged, have become dangerous sites of health problems related to bad air quality.
Volatile organic compounds (VOCs) are a large group of carbon-based chemicals with the tendency to evaporate easily at room temperature. When released to the atmosphere, they can act as significant precursors of photochemical reactions to form hazardous indoor air pollutants, with well-documented adverse health effects [1]. Common symptoms include headache, vertigo, respiratory problems like asthma, skin irritation, hypersensitivity to odors and tastes, but also acute effects related to personality change or cancer depending upon toxicological characteristics of the hazardous substances, duration or frequency of exposure, people's age, and other related factors [2]. A proper reduction of VOC emissions is needful in order to decrease the atmospheric levels as well as reduce human exposure to this kind of air pollutants, thus reaching effective health protection measures. For this purpose, it is necessary to develop adequate highly-sensitive low-cost gas sensors and devices able to monitor and control the emissions of harmful substances even at ultra-low concentrations [3,4].
Gas sensitive field effect devices based on silicon carbide (SiC) have over the last years shown good possibilities of realizing sensors for high temperature applications such as combustion control or monitoring of car exhaust after-treatment systems [5], mainly taking advantage of the wide band gap and chemical inertness of the semiconductor material. The same properties are, however, also beneficial to certain room temperature applications such as environmental monitoring and control, especially when targeting VOCs.
In this study we show how iridium-gated silicon carbide field effect transistors (SiC-FETs) can be used as highly-sensitive low-cost gas sensors for the detection of ultra-low concentrations of specific VOCs, for indoor air quality monitoring and control. Formaldehyde, naphthalene and benzene were used as typical VOCs.
Gas tests were carried out at three different temperatures, 260°C, 300°C and 330°C, in dry air and under effect of 10% and 20% relative humidity (r.h.). For all gas measurements Ir-gated SiC-FET gas sensors operated in a constant current mode measuring the drain-source voltage as the sensor signal [6].
The sensor performance and characteristics were studied in terms of sensitivity, detection limit, long-term stability, response and recovery times, reproducibility, repeatability, temperature dependence and effect of relative humidity.
The best operating conditions were found at 330°C at a gate bias of about 2V. In such conditions, we investigated the effect of r.h. up to 60% especially in terms of detection limit. A significant dependence on r.h. appeared only in the case of formaldehyde, lowering the sensitivity from 45 mV/ppb (detection limit 0.2 ppb, response time 1 min) in dry air to 0.4 mV/ppb under 10% r.h. (detection limit 10 ppb, response time 12 min), see Figure 1.

Naphthalene was detected down to 0.5 ppb with a sensitivity of 36 mV/ppb under 20% r.h. (response time 2 min) and down to 5 ppb under 60% r.h. with a sensitivity of 0.4 mV/ppb (response time 5 min), whilst benzene down to 0.5 ppb with a sensitivity of 6 mV/ppb under 20% r.h. (response time 4 min) and down to 3 ppb with a sensitivity of 0.3 mV/ppb under 60% r.h. (response time 18 min). Results are summarized in table 1.
Surface characterization by atomic force microscopy did not reveal any significant surface degradation due to prolonged exposure to VOCs and high operating temperature.
To get further, new sensing materials as well as smart sensing and data evaluation will be needed in order to differentiate between the VOC components.

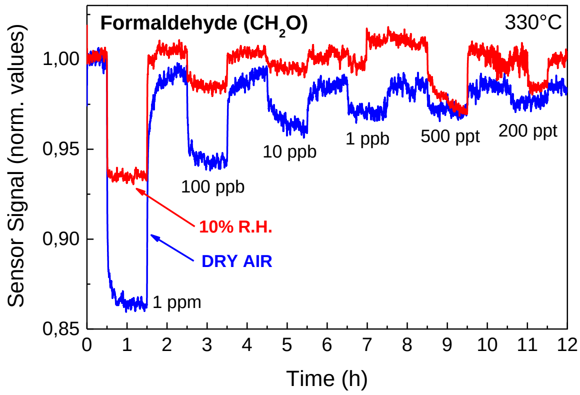

Figure 1. Response of a Ir-gated gas sensitive SiC-FET based sensor to ppb and ppt concentrations of formaldehyde, at 330°C in dry air and under 10% of relative humidity.

Table 1. Sensor's characteristics at 330°C and under different levels of relative humidity.

	FORMALDEHYDE		**NAPHTHALENE**		**BENZENE**	
	Dry air	**10% r.h.**	**20% r.h.**	**60% r.h.**	**20% r.h.**	**60% r.h.**
Sensitivity (mV/ppb)	45	0.4	36	0.4	6	0.3
Detection limit (ppb)	0.2	10	0.5	5	0.5	3
Response time (min)	1	12	2	5	4	18

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Oral Presentation

ELECTRODEPOSITED NANOSTRUCTURED MATERIALS FOR GAS SENSING

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Nanostructured metal oxides for gas sensors have been frequently investigated since they offer several advantages, such as the increased surface area–volume ratio and new reactivity properties, resulting into improved sensing performance levels, as the sensitivity and the selectivity of the detection, as well as the response and recovery time [1-2]. In the last decades, gold nanoparticles (Au NPs) have been extensively utilized as active materials in catalysis, optics, microelectronics, sensor technology, etc., owing to their outstanding size and shape dependent physico-chemical properties [3]. The reactivity of Au NPs dramatically changes as a function of the morphology, composition, and crystalline structure [4]. Recently, hybrid systems consisting of Au NPs dispersed in nanostructured sensing materials, such as metal oxides (MOx), have attracted much interest in improving the gas sensing performance [2, 5-6]. In particular, considering the metal-decorated MOx, they have physical properties that differ from those of the single phase MOx: the presence of catalytic metal nanoparticles increases the surface reactivity and improves gas diffusion inside the active layer; moreover, NP-induced catalytic effects can modify the analyte–active layer chemical interactions and enhance the kinetics of the sensing process [7]. The interfacial region between metal nanoparticle and sensing material has a different electron band structure which also contribute to the unique gas sensing properties of this type of hybrid nanocomposite systems [8].

In the present study, Au NPs with controlled dimension and composition have been prepared by sacrificial anode electrolysis (SAE) in the presence of cationic surfactants. As a result, the electro-synthetized NPs possess a core-shell structure in which a metal core is surrounded by a monolayer of the surfactant. This one-step strategy was firstly proposed by the group of M.T. Reetz to produce highly reactive metal catalysts for organic synthesis applications [9]. In the present study, the SAE method has been modified in order to deposit stabilized Au NPs directly on the surface of nanostructured MOx powders (Fig.1a). Prior to the SAE step, the MOx nanophases have been synthesized by sol-gel methods, and then subjected to thermal annealing prior to the electrosynthesis step. The surface availability of hydroxyl groups on the MOx nanoparticles was found to strongly influence the electro-decoration step introducing surface Au nanophases [10]. The resulting hybrid nanocomposites were thermally annealed under mild conditions and, subsequently, they were morphologically and chemically characterized using scanning and transmission electron microscopies, as well as X-ray photon electron spectroscopy which revealed the formation of nanoscale gold, and its successful decoration on metal oxide nanoparticles (Fig. 1b). Metal ultrafine nanoparticles were shown to be homogeneously dispersed on the larger MOx nanophases. Despite the thermal treatments, elemental gold was proven to be by far the most abundant (>95%) Au chemical environment in the surface of the final nanocomposites.

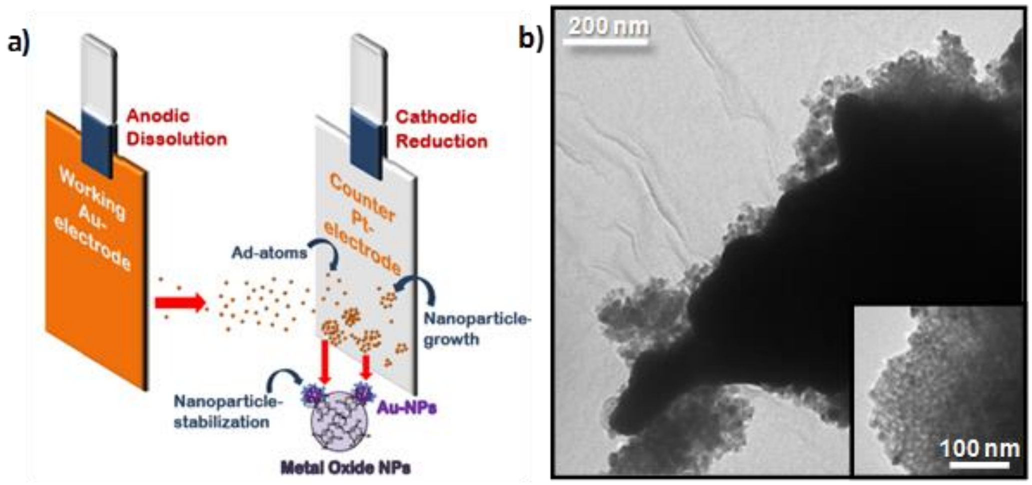

Figure 1. a) A scheme of the SAE in a three electrode cell (the reference electrode is not shown here). b) TEM images at different magnification of electrochemically Au NPs-decorated MOx NPs.

Based on the characterization results, and on previous studies on the detection of nitrogen oxides (NOx) by AuNP-based capacitors [11], we envisage the application of Au NPs-decorated MOx composites as active layer in gas sensing devices. Work is in progress to define the best performing device configurations for the selective detection of environmental pollutants such as NO_x.

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Invited Talk

LOW POWER AND PORTABLE ALGAN/GAN BASED SENSOR SYSTEMS FOR AIR MONITORING

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Abstract
We are developing two sensor platforms for environmental monitoring. For portable air monitoring sensor systems, requirements to be fulfilled are low power sensitive operation and small form factor. The sensor platforms are based on AlGaN/GaN HEMT and electrochemical sensors. The 2DEG formed at the interface between GaN and AlGaN layer is very sensitive to gas absorption at the interface of the AlGaN layer. At the moment the development is focussed on NO_2 detection at ppb level.

AlGaN/GaN based sensors
There is a high demand for NO_2 monitoring devices, which combine sensitivity and selectivity with compactness, portability and low cost. NO_2 is a major air pollutant that is subject to environmental regulation. We develop sensors meeting these criteria based on AlGaN/GaN hetero junctions. Recent developments in the growth of epitaxial III-nitride layers on Si(111) substrates (8") allow for large scale production of devices with a highly mobile two dimensional electron gas (2DEG) formed at the interface between GaN and AlGaN. The sensitivity of these open gate devices can be tuned to the low-ppb range by precise recessing of the AlGaN sensitive area [1]. This allows for the detection of NO_2 at low ppb levels. In figure 1, the sensor response of NO_2 is shown in 50% relative humidity (RH). The NO_2 sensing mechanism of recessed AlGaN/GaN hetero-structures is attributed to the interaction of NO_2 with surface donor states. The response and recovery of the sensor can be accelerated by slope detection and heating. This speeds up the response time from 30 minutes to tens of seconds. For this purpose membranes are formed by DRIE etching of the silicon substrate, to minimize power consumption of the sensor during heating.
The sensors were benchmarked in a field trial with a commercial large and expensive chemo-luminescent analyser and show comparable sensitivity and response time up to low ppb levels. To cover large areas the development of a low-cost environmental sensor that can be operated in a network is of high interest. The GaN sensor can be read-out with a resistive method and we have developed different solutions. A wireless resistive read-out based on TI's microcontroller MSP430 with temperature and humidity compensation is developed. Another solution with Bluetooth communication with a smartphone using Arduino Uno platform is also available (see figure 1c).
The extension of this platform for the detection of other gases/vapours will be explored by temperature modulation and functionalization of the AlGaN surface. High temperature detection with the use of micro-hotplates is a possibility to detect e.g. volatile organic compounds at specific temperatures. We will investigate the feasibility of surface functionalization using thin metal oxide layer (ALD) in combination with catalyst particles.
The purpose of functionalization is to improve the selectivity and sensitivity towards different gasses. This may be achieved for example by coating the surface of the gate region with sensing layers that interact with gas species resulting in the formation of surface dipoles or charges. In the scientific literature, a variety of gas sensors based on GaN HEMT technology have been demonstrated with proper surface functionalization on the gate area of the HEMTs, for the detection of gases (e.g. H_2, NH_3, CO, CO_2) [2, 3, 4, 5, 6, 7]. For example, porphyrins

can form complexes with metal ions, which are ligated to the four nitrogen atoms in the central cavity. These metalloporphyrins can bind gas molecules to the metal ion, forming a dipole [8]. As the nature of the 2DEG at the AlGaN/GaN heterostructure originates from the polarization of the structure itself, the material is uniquely suited for the detection of surface dipoles. We show that these metalloporphyrins can be used to detect NO.

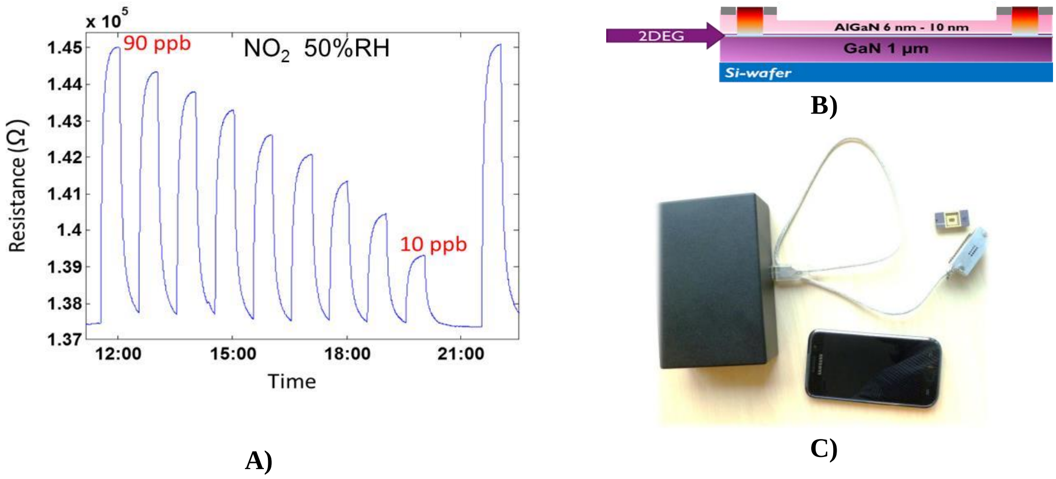

Figure 1: A) Sensor response for decreasing NO_2 concentrations in N_2 measured in 50% RH at elevated temperature (~200C). B) Schematic of the recessed open gate AlGaN/GaN HEMT structure on Silicon. C) Photograph of a sensor chip wire bonded in a DIL package. The black box contains the read-out electronics, heater and wireless communication with mobile phone.

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CMOS-BASED SENSORS FOR UBIQUITOUS GAS DETECTION: CHALLENGES AND OPPORTUNITIES

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Abstract
An ever increasing demand for sensors in the consumer, industrial, automotive, and healthcare markets is driving forward technological advances in ubiquitous sensors for a wide range of new applications [1]. The very high volumes and low unit cost required is largely made possible by the implementation of MEMS technologies; thereby allowing incorporation into smartphones and tablets. The resultant sensors are ubiquitous cloud-enabled sensors by exploiting 3G/4G, wi-fi, bluetooth and other wireless communication networks for sensor data management and smart signal processing [2]. In this paper we address the need for ubiquitous gas sensors, and concentrate specifically on the progressive miniaturisation of gas sensors based upon CMOS, MEMS technology developed and patented [Reg no: 2464017, 7495300, 06765348.5] by Cambridge CMOS Sensors (CCMOSS); thus enabling high volume, low cost production capabilities for ubiquitous gas sensing applications. In particular, we explore the challenges and opportunities associated with high volume production (>100 M units/year) of CMOS, MEMS technology-based gas sensors and present this in context of supply chain process flow. Figure 1 and 2, shows an overview of the supply chain process steps or typical development stages and options that has been established for production of CMOS-based gas sensors (CO, VOC, Alcohol) for high volume manufacturing.

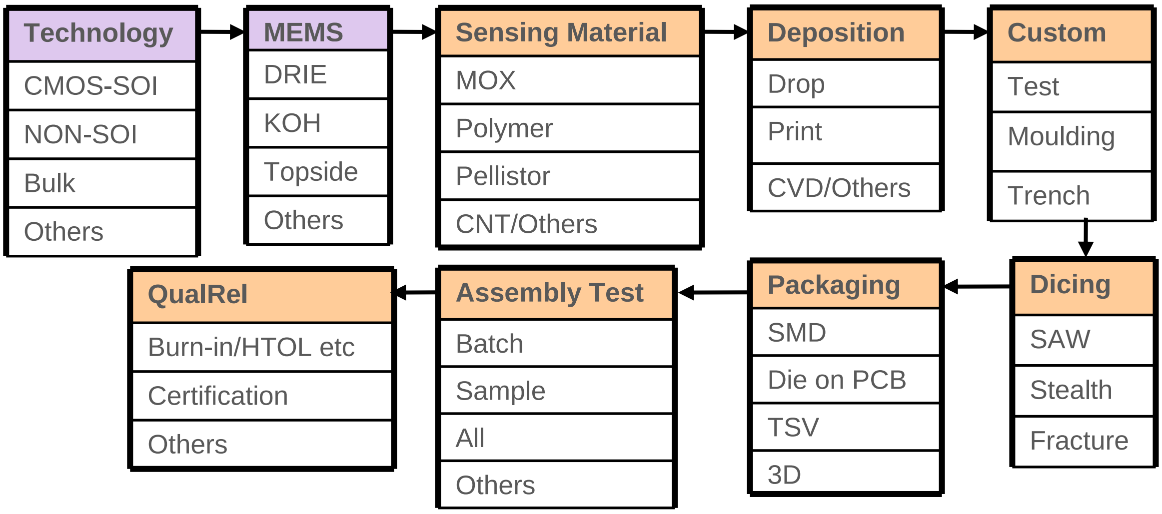
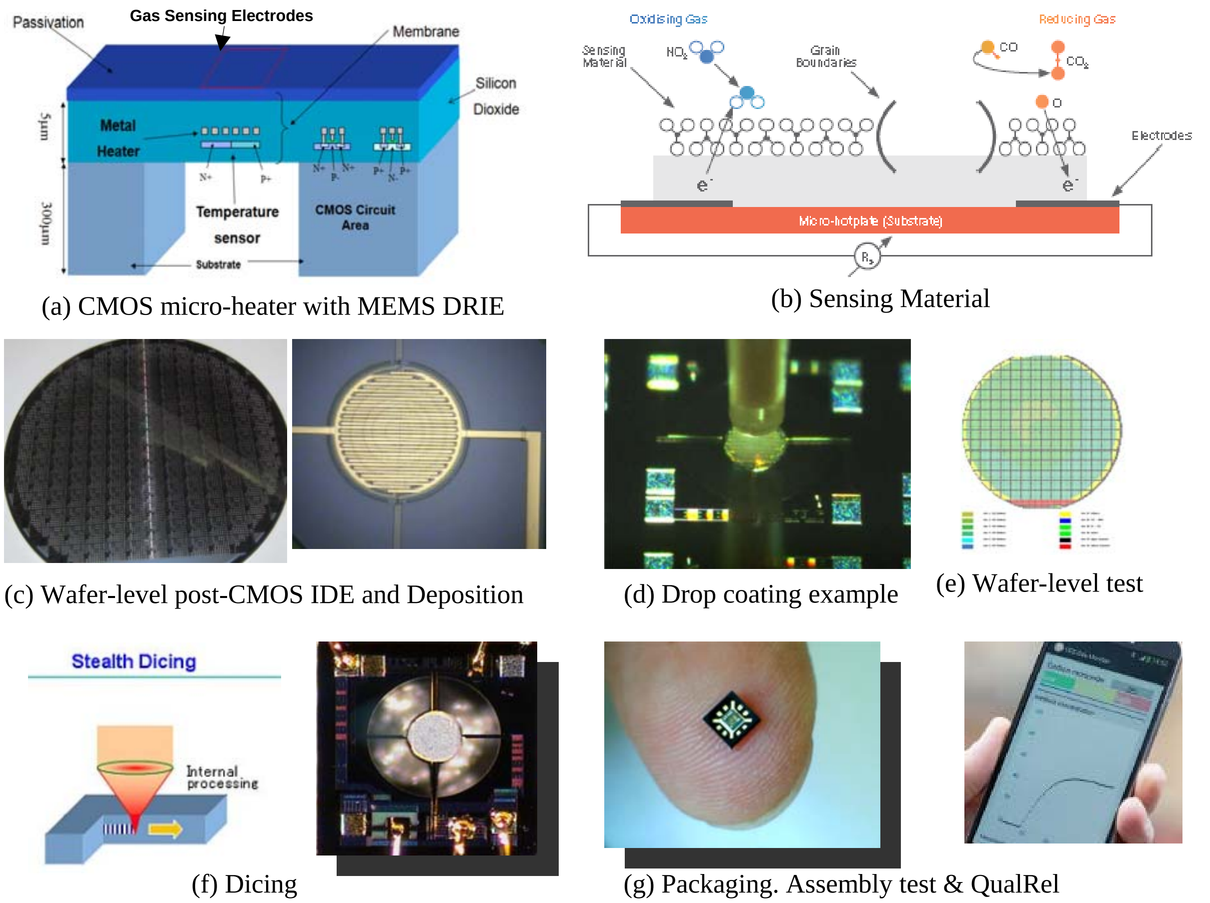


Figure 1: Supply chain for MEMS CMOS-based Ubiquitous Gas Sensor Production

Technology developed for miniaturising the heating elements (aka micro-hotplates) by CCMOSS is based on standard SOI-CMOS process. The method and concept used has been published in [3,4]. The core technology offers high temperature (> 600ºC) tungsten metallisation and especially developed DRIE, MEMS process at a commercial foundry, which is used for the design of the micro-hotplates. In terms of ubiquitous exploitation of technology, a number of different problems have been solved, perhaps the most critical ones being: reliability, thermal uniformity, reproducibility, stability, low power consumption, and high yield. Furthermore, for consumer market applications, and depending of volume threshold, when a SOI-CMOS process does not provide the cost advantage, we have also developed alternative bulk silicon (i.e. non-SOI) options as well as process migration capabilities to lower geometry. Results of the bulk process do not show any performance degradation, in terms of power consumption, reliability and thermal transient response – the factors that are critical for commercial deployment of this technology.



(a) CMOS micro-heater with MEMS DRIE
(b) Sensing Material
(c) Wafer-level post-CMOS IDE and Deposition
(d) Drop coating example
(e) Wafer-level test
(f) Dicing
(g) Packaging. Assembly test & QualRel

Figure 2: Examples of process flow for CMOS-based ubiquitous gas sensor production

Conclusions

We have shown that to meet the demand for high volume (greater than 10 million sensors per month), the best option is to capitalise on mature CMOS technology for current and future miniature gas sensing applications. Working with commercial foundry partners CCMOSS has developed process flows where all major post-CMOS tasks are done at the same foundry. Furthermore, we have addressed adhesion, deposition and reliability issues to achieve enhanced performance and enabled multi gas sensing capabilities by incorporating an array of 2×2 sensors on a single 1 mm × 1mm die. To enable ultra-miniaturisation of the sensors, leading edge technologies employed through our high volume packaging and test partners.

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Oral Presentation

GRAPHENE FOR GAS SENSORS

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Abstract
Graphene is a monolayer of sp^2 hybridized carbon atoms, tightly packed into a two-dimensional honeycomb lattice, whose amazing properties allow, in principle, a huge range of applications [1]. Besides optical, electrical, mechanical and thermal properties, the planar nature of the lattice, which exposes all of its atoms to the environment, provides the highest value of surface to volume ratio [2]. The combination of this property with the highest carrier mobility and lowest resistivity value, has pushed researchers into investigating graphene potential in chemical sensors field [3]. Indeed, after the first experimental evidence that a graphene flake can detect the presence of even a single interacting molecule [4], many theoretical and experimental studies have shown that graphene-based chemisensors operating at room temperature possess pronounced sensitivity to certain analytes (e.g., NH_3, CO, NO_2, SO_2, H_2O). More specifically, the detection of NO_2 has achieved an extremely low limit, below the sub-ppm (parts per million) range, but in some cases graphene was prepared by laborious and expensive techniques, such as chemical vapour deposition or epitaxial growth, or by chemically exfoliating graphite oxide, which requires toxic and costly chemicals for pre- and post-treatments [2, 5-8]. In other cases, specific measures, for instance continuous exposure of the sensitive material to ultraviolet light, were adopted to reach an even lower limit, in the range of ppt (parts per trillion) [9]; in any cases is paid the price of employing time- and energy-consuming systems and/or a more complicated and unwieldy device structure.
Herein we present a graphene-based chemiresistor prepared by a simple, handy and cheap fabrication process, that is the liquid phase exfoliation of graphite by means of green solvents.

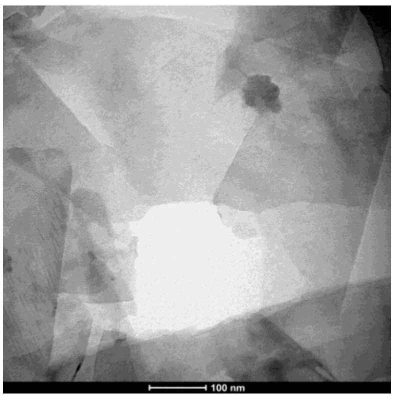
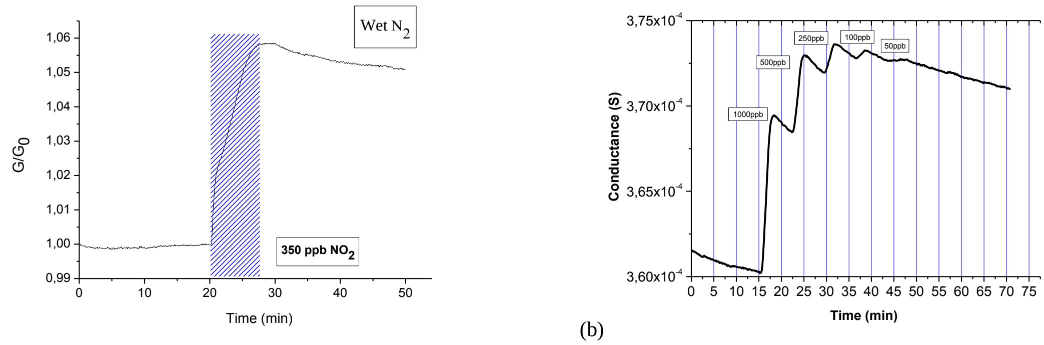


FIG. 1. TEM image of the flakes produced by chemically exfoliated graphene. The mean lateral size of flake is of the order of hundred nanometer.

The device, tested in controlled environment at a room temperature, exhibits high sensitivity towards NO_2. A calibration for gas concentrations ranging from about 100 ppb up to 1000 ppb in controlled conditions of pressure, humidity and temperature will be also presented.



(a) (b)

FIG. 2. (a) Normalized conductance dynamic response of the device upon exposure to 350 ppb of NO_2 in nitrogen atmosphere at RT and RH=50%. (b) Trend of the conductance for different analyte concentrations as function of exposure time.

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COST Action TD1105 *EuNetAir*
2nd International Workshop *EuNetAir*, Brindisi (Italy), 25-26 March 2014

Oral Presentation

DEVELOPING COMPUTATIONAL INTELLIGENCE TECHNIQUES FOR DISTRIBUTED AND MOBILE AIR QUALITY MONITORING

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Abstract

Air quality smart multisensors device are thought to be the major solution to improve spatio temporal density of the air quality monitoring network of our cities. Their development is also thought to be a major enabler for several other application like air pollution personal exposure monitoring, heavily distributed olfactive nuisance monitoring and source declaration, smoldering and illegal fires detection, etc. Unfortunately most of the sensing device they rely on suffers from trade offs arising among several requirements like specificity, sensibility and stability. This issue has been found to apply constantly over the years, unrespective of the technology (MOX, EC, etc.) that is at the base of their transduction mechanism. Another major issue is represented by lack of repeatability in fabrication. This is often neglected but of course it represent a source of significant costs for the commercialization of calibrated multisensory device since basically, every device is then characterized by a slightly different calibration curve. Together, all these factors account for each multisensor device to be a unique device causing strong difficulties in the calibration of large number of multisensory devices.

Our group is involved, since many years, in the investigation of the possible roles of computational intelligence techniques in the development of autonomous, intelligent multisensory devices for massively distributed air quality monitoring applications. In the last decade we have successfully developed machine learning techniques for on-field calibration of gas multisensory devices testing this methodology with significant data streams [1]. In this approach, the multisensory device is collocated with a stationary conventional multi gas analyser in order to compare its response to the response of the conventional analyser. A multivariate calibration based on ANN and SVM models has been applied to allow for cross interference effects reduction on the concentration estimation. Optimal length of the calibration dataset has been studied with 10 days seeming to provide adequate coverage for weekly cyclostationarity of the pollution process.

A step further have allowed to embed the developed computational intelligence on-board of a smart device for sensor censoring and energy saving by avoiding unnecessary transmissions. This may provide an interesting solution for distributed safety monitoring scenarios, mobile systems and personal exposure assessment device [2][4]. More recently, we have tackled the concept drift related issue by developing a Semi-supervised learning techniques that has shown capable to reduce the effect of the environmental variations over a one year long dataset produced with a Pirelli prototype multisensory device [3]. Currently we are testing the same methodology on further datasets. As a secondary but not less interesting benefit, we have obtained the possibility to significantly reduce to 24hrs the dimension of on field data to be recorded for supervised training, allowing the algorithm to learn weekly obscillations by unsupervised samples. However, the drift negative effects have only been reduced and beside the basic idea have shown to work further development are needed. At the moment we are facing Calibration transfer issue in order to cope with the sensor characteristics variation issue that appear to be still mainly open and to be very significant for the envisaged heavily distributed and pervasive monitoring scenarios [5]. In our communication we will stress how

our experience have thought us about the use of computational intelligence techniques in this scenarios. It emerges that this techniques can play a major role in the development of next generation air quality monitoring devices. However, a major drawback for the development of an adequate comparison of multiple techniques is the lack of an adequately large set of shared datasets upon which to test the developed methodologies. This issue has, in our opinion, hampered the speed of new developments in this field, as such we believe that the availability of new datasets may allow for a more thoroughly and significant assessment of the potential of computational intelligence techniques in our field.

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ABSTRACTS OF POSTER PRESENTATIONS

Poster Presentation

ELECTROPHORETIC GOLD NANOPARTICLES DEPOSTION ON CARBON NANOTUBES FOR NO_2 SENSORS

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Carbon nanotubes (CNTs) have attracted considerable attention as gas sensing materials because of a number of exceptional properties, which include a high aspect ratio, and excellent chemical and environmental stability. These properties make them ideal candidates for detecting gases [1]. CNTs have the ability to detect individual reactions when a gas molecule attaches or detaches from their surface. The adsorbed/desorbed gas molecules can change the carrier (hole, electron) density in CNTs, which results in a change in resistance of CNTs. In addition, the electronic properties of CNTs change remarkably when exposed to a target gas, inspiring the basic principle for the application of CNTs to gas sensors [1]. Recent studies have shown that the addition of metal or metal oxides to CNTs dramatically increases the sensitivity of the gas sensor. Metal or metal oxide nanoparticles have superior physico-chemical properties, such as high activity with gas molecules, good adsorption/desorption capacity and efficient charge transfer [2]. Therefore, the addition of metal or metal oxides can give a CNT-gas sensor a full range of reactivity towards different gases [3]. In particular, nanoparticles can provide a continuous pathway for moving carriers, between CNTs, where sensitivity can be improved by the presence of both the nanoparticle surface and the charge transfers between the CNTs and nanoparticles induced by gas adsorption/desorption [4]. Metal nanoparticles were coated on the CNT surface, leading to the successful approach [3]. In the present study, the impact of the tailored load of gold nanoparticles (Au NPs) functionalizing the sidewalls of CNTs networks on NO_2 gas sensing performance of a resistive gas sensor, operating at a working temperature in the range of 100-200°C, was investigated. CNTs films have been deposited on alumina substrate by radiofrequency plasma enhanced chemical vapour deposition (RF PECVD) technology [5]. Considering the recent interest in the use of CNTs from both an electrochemical point of view and as metal nanoparticle catalyst supports, it is somewhat surprising to find so few examples of electrochemically controlled metal nanoparticle deposition on CNTs in the literature [6].

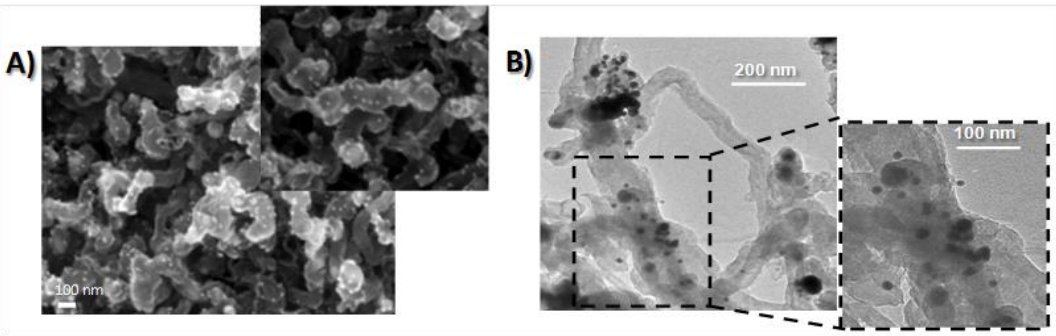

Figure 1. A) SEM and B) TEM images of electro-decorated CNTs with Au NPs.

In this study an electrophoretic deposition of Au NPs on CNTs has been performed to modify CNTs surface to improve the sensitivity and selectivity for NOs gas detection up to sub-ppm level. SEM and TEM images in Figure 1 revealed the presence of nanoscale gold and its successful deposition on CNTs. Au NPs/CNTs hybrid system exhibited a p-type response with a decrease in electrical resistance upon exposure to oxidizing NO_2 gas, as reported in Figure 2, and an increase in resistance upon exposure to reducing gases like CO. An optimal Au NPs loading and operating temperature for Au NPs modified CNTs-sensor exposed to NO_2 gas has been recorded.

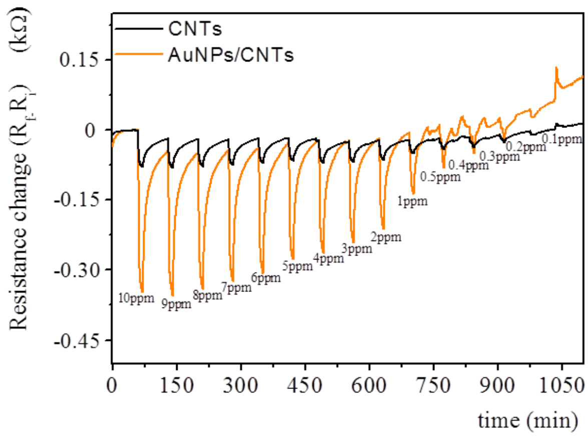

Figure 2. Resistance change of CNTs and Au-decorated CNTs at different NO_2 concentration at operating temperature of 150°C.

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Poster Presentation

Pd-Doped ZnO Nanorods for VOCs Sensing

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Abstract

In this study, gas sensors were fabricated on quartz crystal microbalance with coating of ZnO and palladium doped ZnO nanorods for volatile organic compounds (VOCs) at room temperature. Vertically aligned doped and undoped ZnO nanorods were synthesized on each sides of QCM by using solution based process. The diameters and length of doped and undoped ZnO nanorods were 100 nm and 600 nm, respectively. Sensor responses of samples were enhanced with increasing of Pd doping concentrations and samples were more sensitive to ethanol vapour than methanol vapour even at low concentration of ethanol. Semiconducting metal oxide materials have good thermal stability, mechanical and chemical durability even at harsh environment. Thin and thick film and nanostructures of semiconducting metal oxide materials as zinc oxide, tin oxide, tungsten oxide, etc. have been used in gas sensors as sensitive. Among these structures nanomaterials have present high surface to volume ratio and higher surface areas of sensitive layer. With increasing of the surface area, sensing properties of gas sensors can be improved which have been presented by research groups [1]. In generally, most of semiconducting metal oxide based sensor applications, changing in the electrical properties of semiconduting metal oxide materials (conductance, resistance and capacitance) are used for detecting of gas species. Electrical properties of these materials can easily be altered depends on changing gas concentration of surrounding ambient especially at elevated temperatures depends on chemical reactions between target gas species and sensitive layers [2-3]. ZnO is a n-type semiconducting materials with wide and direct band gap. Comparing to other metal oxide materials, ZnO has many disadvantages, low selectivity and sensitivity and high operation temperature on the other hand advantages are fabrication of nanostructured forms are easier and its selectivity and sensitivity can be modified with doping of catalyst materials [2-4]. Doped and undoped ZnO nanorods were fabricated on gold electrode coated QCM transducers by solution based method [5]. The resonance frequency of QCM transducers was 10 MHz. Doping concentration of Pd in ZnO nanorods were arranged with varying of the composition of solution used in electrochemical deposition process. Pd doping concentrations in ZnO nanorods was 0.02%, 0.5%, 1.5% and 2.5%. Fabricated ZnO nanorods have 100 nm in diameters. Scanning electron microscope images of ZnO nanorods were given in figure 1.

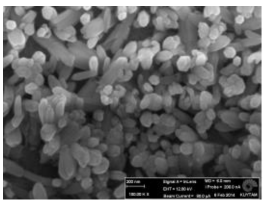
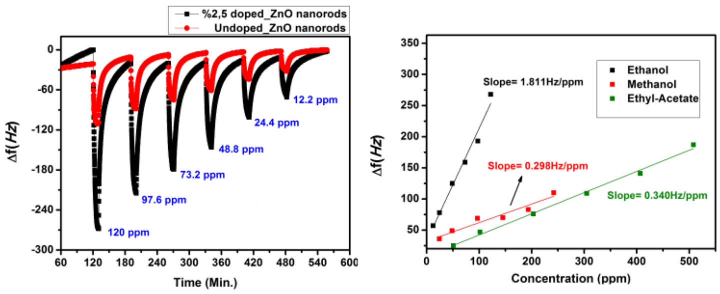


Figure 1. SEM images of ZnO nanorods.

Fabricated samples were tested to VOCs in dry air ambient at room temperatures. Ethanol, methanol, ethylacetate were chosen as analytes. The test concentrations were 120 ppm - 12 ppm for ethanol, 240 ppm - 24 ppm for methanol and 500 ppm - 50 ppm for ethyl acetate. Sensor responses increased with increasing of Pd doping concentrations. The sensors responses of 2.5% Pd doped doped and undoped of ZnO nanorods to ethanol vapour as function of a time were given in figure 2a and sensor responses of 2.5% Pd doped ZnO nanorods for selected analytes as a function of concentration were given in figure 2b.



a) b)

Figure 2. a) Sensor responses of 2.5% Pd doped and undoped ZnO nanorods to ethanol vapor, b) Sensor responses to selected analytes (in dry air) as a function of concentration.

As a conclusion, fabricated samples were more sensitive to ethanol vapour than other two types of volatile organic compounds and sensitivity of ZnO nanorods increased depends on Pd concentration in nanostructures.

Acknowledgement:

This study was partly supported by The Scientific and Technological Research Council of Turkey. Project title: "*Development of Automotive Gas Sensors Based on Nano-Metal-Oxide Semiconductor with increased Selectivity, Sensitivity and Stability*" and project number "111M261" and supported by COST Action TD1105 *EuNetAir - European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability* - by a Short Term Scientific Mission Year-2 (STSM-TD1105-16434, period from 03-03-2014 to 28-03-2014): "*Functionalization of ZnO Nanorods With Metals and Metal Oxides For Gas Sensing Applications*".

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Poster Presentation

ZnO NANORODS FOR GAS SENSORS

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Abstract

In recent years applications of nanostructured ZnO, particulary nanorods, in gas sensors, dye sensitized solar cells, field effect transistors have attracted increasing interest [1-3]. One-dimensional nanowires and nanorods (NRs) can be grown from gaseous phase or by wet chemical methods [4]. The gas-phase methods require relatively high growth temperature, expensive equipment and source materials. The wet chemical methods have several advantages as compared with gas-phase methods. They are inexpensive, less hazardous, the growth takes place at lower temperature, the morphology can be easily controlled and large areas of a wide variety of substrates can be homogeneously covered [5].

In this work ZnO NRs were synthesized by hydrothermal method from aqueous solution of zinc nitrate hexahydrate ($Zn(NO_3)_2 .6H_2O$) and hexamethylenetetramine (HMT) at 95 °C [6]. Thermal degradation of HMT releases hydrozyl ions, which react with Zn^{2+} ions and form ZnO [7]. The scanning electron microscopy (SEM) image of the NRs prepared on hydrothermally grown seed layer is shown in Fig. 1.

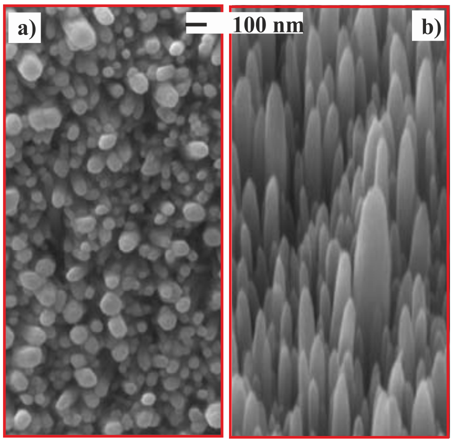

Figure 1. SEM images of ZnO NRs. (a) - top view and (b) – images taken at a 55° tilt.

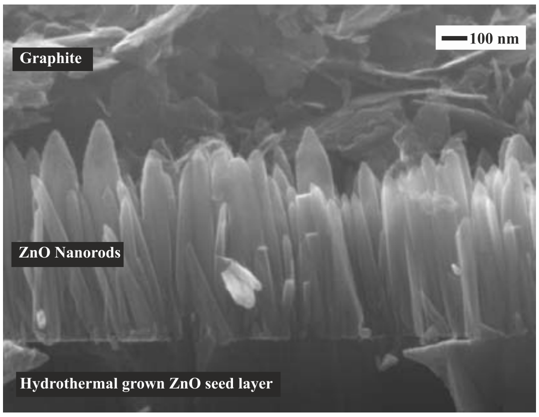

Figure 2. Cross section of graphite/ZnO NRs Schottky diodes.

In our previous works we presented that highly rectifying and thermally stable Schottky contacts can be created by depositing colloidal graphite [8-10]. We apply this technique to create a Schottky contact on the layer of the ZnO NRs. Before the growth of ZnO NRs, a small portion of the seed layer was covered by a photoresist. The photoresist was then removed to create a Ga-In ohmic contact. As shown in Fig. 2, the layer of colloidal graphite consist of irregular flakes of sizes in the range of about 1 μm. The relatively big graphite flakes thus do not penetrate the area between the NRs and avoid potential short-circuiting. The graphite/ZnO NRs structures were tested for their sensitivity to hydrogen in the cell with a through-flow gas system. The effect of hydrogen exposure on the I-V characteristics of the graphite/ZnO NR Schottky diodes is shown in Fig. 3. The reverse current increases on exposure to hydrogen. It is known that oxygen molecules adsorbed on the surface extract electrons from the conduction band of ZnO to form O^- and O^{2-} anions. This process leads to the formation of a depletion region with reduced carrier concentration near the sample surface. When exposed to hydrogen, chemisorbed oxygen species react with hydrogen, the extracted electrons are released to the conduction band, and resistivity is decreased [11].

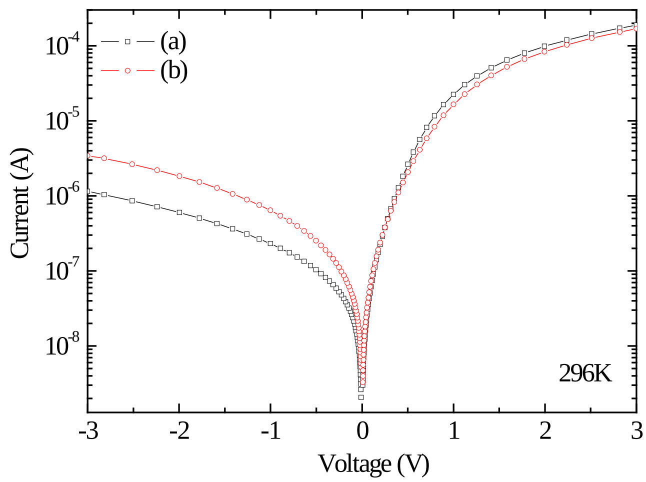

Figure 3. (a) Current-voltage characteristics of the graphite/ZnO NRs Schottky diode. (a) in air, (b) under exposure to 0.1% H_2 in N_2.

The work was supported by EU COST Action TD1105 – project LD14111 of the Ministry of Education CR.

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Poster Presentation

NANOSTRUCTURED SCHOTTKY CONTACTS FOR GAS SENSORS

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Abstract
Hydrogen gas has been widely used in chemical industry, medicine, or hydrogen-fuelled vehicles. However, hydrogen is volatile and extremely flammable. A small leakage of high concentration of hydrogen-containing gases can cause explosion. Development of hydrogen sensor with high sensitivity, short response time, small size and low cost is in great demand. In recent years, there were many attempts to apply metal/InP structures in hydrogen sensors. Conventional metal deposition techniques resulted in poor quality metal interfaces and low sensitivity [1]. Substantial improvement of the interface quality, and consequently of the sensing properties, was achieved by using electrochemical techniques for the deposition of the catalytic metal [2, 3]. Further improvement in sensing properties can be achieved by reducing the metal grain size. The electrophoretic deposition (EPD) is appropriate for the fabrication of the nanostructured Schottky contacts by the deposition of a catalytic metal in the form of nanoparticles (NPs).
We compare sensing properties of Schottky diodes created by (a) EPD of a thick layer (~100nm) of Pt NPs on InP substrate (Fig 1a); and by inserting a submonolayer of Pt NPs between the graphite and InP substrate (Fig. 1b). Pt NPs with the average diameter of 5 nm dispersed in isooctane solution were prepared by the reverse micelle technique [4]. Sensor elements prepared in this way are capable of detecting of low concentrations (about 1ppm) of hydrogen at room temperature [5-7].

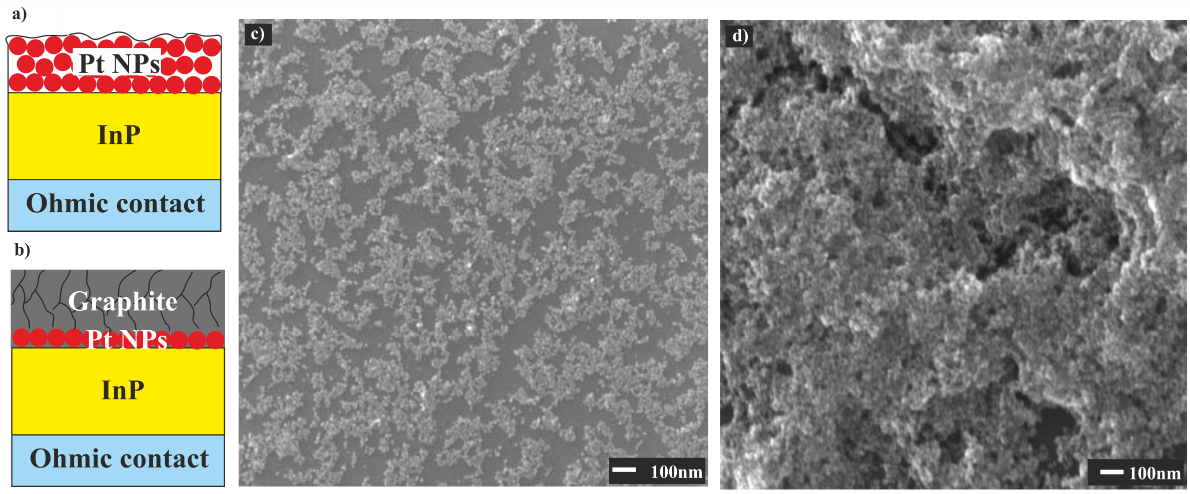

Figure 1. Schematic cross-section of (a) Pt NPs/InP and (b) graphite- Pt NPs/InP Schottky diodes. SEM images of (c) submonolayer and (d) thick layer Pt NPs deposited on a semiconductor substrate by EPD.

Current voltage and current-transient characteristics for both structures are presented in Fig. 2. It is known that molecules of hydrogen adsorb onto the surface of the catalytic metal (Pd,Pt) and dissociate into hydrogen atoms. Hydrogen absorption can affect different properties of this metal such as the work function, conductivity, lattice constant and optical properties [8]. The sensing properties can be explained by the diffusion of hydrogen atoms through the metal film and their absorption at the metal–semiconductor interface. Hydrogen absorption leads to the formation of the dipole layer, which changes the SBH and results in the increase of both forward and reverse current [9].

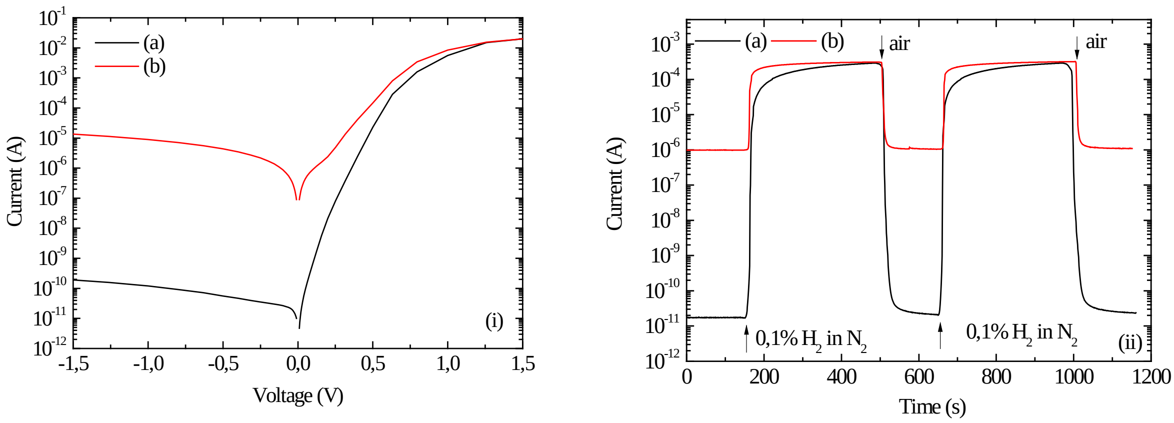

Figure 2. Comparison of current–voltage (i) and current transient measured at -0.1V (ii) characteristics of the (a) graphite-Pt NPs/InP and (b) Pt NPs/InP Schottky diode.

The work was supported by EU COST Action TD1105 – project LD14111 of the Ministry of Education CR.

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