NEWSLETTER ISSUE 1

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Editorial

By Andreas Schütze, Project Coordinator

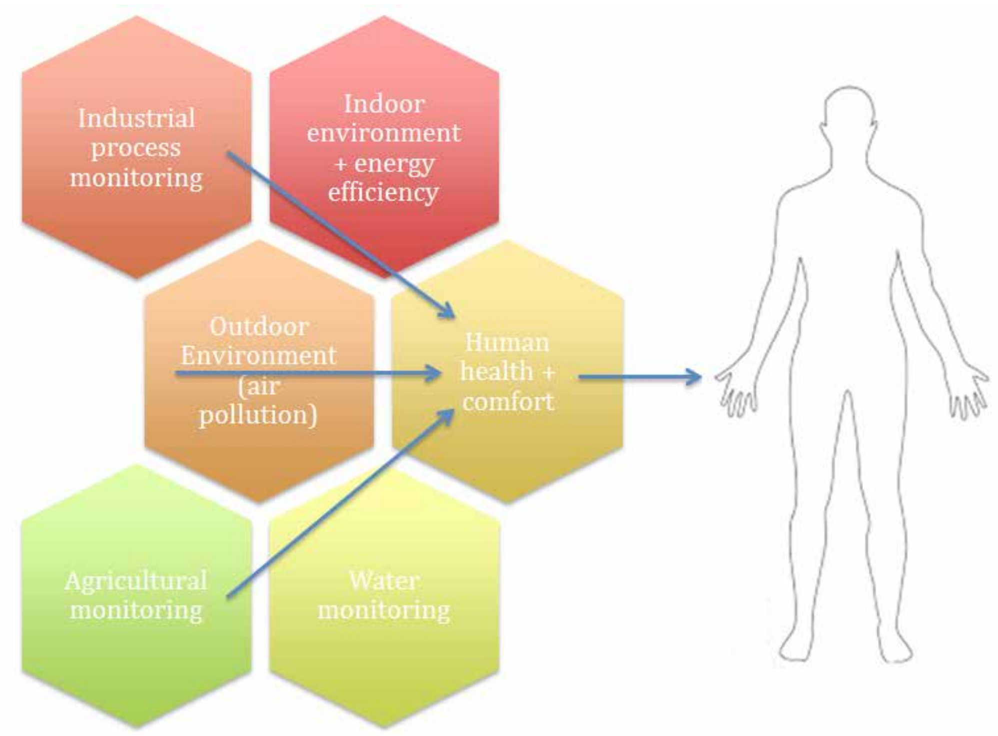
The SENSIndoor project combines all aspects that make R&D fun and worthwhile: in this single project, the partners try to bridge the gap from basic research in modern nano- and microtechnology to applications with an impact on everyday life.

In this R&D micro cosmos researchers from three universities and one research institute work together with six SMEs to develop novel nanotechnology based intelligent sensor systems for selective monitoring of Volatile Organic Compounds for demand controlled ventilation in indoor environments. The expected impact is twofold: 1) greatly reduced energy consumption in buildings contributing to sustainable development in Europe and worldwide and 2) improved air quality to avoid the Sick Building Syndrome. The SENSIndoor sensor systems will allow optimized ventilation adapted to specific application scenarios like offices, hospitals, schools, nurseries or private homes.

The SENSIndoor project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 604311.

Priority scenarios and corresponding target gases and concentrations were defined together with an advisory board representing health standard experts and major industrial stakeholders. This has led to interesting meetings with discussions ranging from European air quality policy and standards to characterization and sensor performance of metal oxide nanofoams, -trees and -bushes.

With this first newsletter, we provide an overview of results achieved so far and the goals for the final year of the project to raise awareness concerning the SENSIndoor technology for potential users and to enhance interfacing with other initiatives addressing similar goals and requirements. This newsletter therefore highlights three main technological foundations addressed within the project: a) the PLD process for improved gas-sensitive layers, b) SiC-FET sensors for highly sensitive VOC detection and c) integrated sensor systems combining MOS sensors with innovative MOF pre-concentrators in a low-cost package. A further article addresses potential application areas beyond the primary Indoor Air Quality application addressed in the project. Selected papers showing detailed results – many of them published open access for broad dissemination – are listed to provide a deeper insight into the project and its scientific output.



Vision of the ESSC: contributing to human health and comfort through novel (bio-)chemical sensor systems for various key application areas.

Over the last two years the project partners have interacted with various other projects and initiatives, mainly the COST TD1105 EuNetAir network (www.eunetair.it) from which the project was originally initiated. In the last year,

The SENSIndoor Consortium at the 3rd Progress Meeting in Linköping, Sweden, in June 2015 the new European Sensor Systems Cluster (ESSC, www.cluster-essc.eu) was launched to join efforts in order to avoid defragmentation and to promote synergies with industrial leadership and European cooperation in the field of (bio-)chemical sensor-systems applications.

SENSIndoor is proud to contribute to this initiative by chairing two working groups, Indoor Air Quality (chair: A. Schütze, Saarland University) and Sensor Integration and Commercialization (chair: O. Martimort, NanoSense).

The partners place a high priority on this aspect, as they are aware that achieving the goals of the project is only possible through partnership, exchange and collaboration with others. Novel sensor systems will only succeed if the regulatory framework is right and if systems integrators – for building automation, but also, e.g., transportation – see Indoor Air Quality as a key factor for future success.

Already, we have received many positive comments and requests for further information from around the world and we are looking forward to your feedback

Andreas Schütze is a full professor in the Department of Mechatronics at Saarland University and head of the lab for measurement technology. He received his PhD in Applied Physics from Justus-Liebig-University in Giessen, Germany with a thesis on micro gas sensor systems. After some years in industry, he was professor for Microsystem Technology at the University of Applied Sciences in Krefeld, Germany, before joining Saarland University in 2000. His research interests include microsensors and microsystems, especially intelligent chemical sensor systems for safety and security, renewable energy and optimized energy systems. He is a member of the COST Action EuNetAir and co-founder of the spin-off company 3S, another partner in the SENSIndoor consortium.

Some Personal Reflections on the SENSIndoor Project

By Eberhard Seitz, Project Technical Advisor (PTA)

The SENSIndoor project is one of the very few successful projects – among more than 100 proposals – for one of the last FP7 calls: Nanotechnology-based sensors for environmental monitoring. Congratulations!

SENSIndoor is a "spin-off" of the COST Action EuNetAir. I am happy that the basic-oriented initiative – European Cooperation in the field of Scientific and Technical Research (COST) from the early 1970ies – is still alive and effective. It offers researchers a more bottom-up network for European cooperation, compared to the more top down cooperation within the European Commission programmes. Consequently, EuNetAir members also play a dominant role in the Horizon 2020 initiative "European Sensor Systems Cluster" (ESSC) (www.cluster-essc.eu). The coordinator of the SENSIndoor project, e. g., acts as chairman of the ESSC Working Group II on "Indoor Air Quality". The input for the ESSC vision and roadmap is very welcome for future EC work programmes!

As to my four tasks as Project Technical Advisor (PTA) for the SENSIndoor project, namely "1. review reports and deliverables, 2. keep regular contacts, attend meetings, 3. intervene in case of problems and 4. coordinate with similar projects", there were no reasons for 3. to intervene in case of problems. On the contrary, it has been a pleasure to review reports and deliverables (really, as they are very well written), to keep in touch on a regular basis and to attend meetings (with engaged, competent and friendly people), as well as to coordinate with similar projects (like the other new FP7 indoor air quality sensor project IAQSense (www.iaqsense.eu) and the whole ESSC). Thus I am looking forward to the common session on "Changing the game in the management of Indoor Air Quality – Real time monitoring for improved health, comfort and energy efficiency" at the Indoor Air Conference from July 3-8, 2016 in Ghent.

The 10 partners in the SENSIndoor project, their input to the overall goal of the project and their interaction are well documented in this first of two newsletter issues. Let me instead just mention some personal remarkable impressions. Already at the second progress meeting – after one year – the Functional Electroceramics Thin Film Group at the University Oulu, reported about pulsed laser deposition (PLD) studies for WO3 nano-structured gas-sensitive layers, which allowed the detection of naphthalene in the ppb (!) range. Thus one of the project goals was already fulfilled. Typical for the project strategy – besides sensor system integration (including packaging, electronics and signal processing) as well as calibration options – are successful first steps to achieve a wafer level deposition PLD process compatible to the two sensor technologies addressed within the project: MEMS-based metal oxide semiconductor (MOS) gas sensors and SiC-based gas sensitive field effect transistors (GasFET). Meanwhile, the respective MOS and GasFET sensor elements have reached significantly higher sensitivity and selectivity versus target gases (benzene (down to 1 ppb), formaldehyde and naphthalene) than existing sensors. These tests have been accompanied by promising simulation studies at the Lab for Measurement Technology at Saarland University: depending on the position of (multiple) micro-pre-concentrator(s) with metal organic framework layers – and (multiple) sensors in the reaction chamber a concentration gain of 30 at the sensors after a few seconds might be possible (!)...

On the one hand, these midterm success stories are reassuring. On the other hand, there are national and international bodies (including the World Health Organization) which will raise detection limits for harmful volatile organic compound (VOC) as soon as improved respective sensors are available and as soon as there are increased public and environmental needs. These prospects should encourage the consortium to continue working on its own further improvements.

Public funding requires appropriate information. Thus I am convinced that this Newsletter – as well as the website (www.sensindoor.eu) – form a sound basis for communicating remarkable results: students will be encouraged to join sensor R&D, users will find ample application possibilities and the public will enjoy a future with improved health, comfort and energy efficiency – using these new VOC sensors. I wish this Newsletter the respective resonance it deserves. The interaction with its readers just began...

Eberhard Seitz studied theoretical physics in Bonn and experimental solid state physics at Research Centre Jülich (FZJ), doing neutron scattering experiments in Jülich and in Grenoble. He was Post Doc at UCLA. Back in Jülich he became head of department in the project management agency of FZJ, promoting applied national R&D projects on behalf of the German Federal Ministry of Education and Research in the field of materials; this included a European activity in COST e. g. as chairman of the COST Technical Committee of Materials from 1990-1994; from 2000-2004 he was Seconded National Expert first in the COST Unit, then in the Nanotechnology Unit of the Industrial Technology Directorate of the EC in Brussels. From 2004-2006 he coordinated the ERA-NET Hydrogen and Fuel Cells. From 1996-2014 he taught functional ceramics at the Technical University of Clausthal, where he was appointed Honorary Professor. After his retirement from FZJ in 2006 he became Project Technical Adviser for FP6 and FP7 projects, among them three EU-RU sensor projects: INGENIOUS, SAWHOT, S3, and now IAQSense and SENSIndoor.

SENSIndoor Technology Highlights

Pulsed Laser Depositon (PLD) – Process and Application Areas

By Ville Kekkonen (Picodeon, Finland), Jyrki Lappalainen and Joni Huotari (University of Oulu, Finland)

Pulsed laser deposition (PLD) is a conceptually straightforward material growth technique: a pulsed laser beam is used for removing material from a target and the ejected material is collected and condensed on the surface of a substrate to form a layer of material. Most solid materials can be ablated with laser and can thus be used as a target material. Moreover, the substrate material can be almost anything from hard ceramics to metals to soft polymers. In addition, the energy of the ablated species is usually high, which provides very good adhesion of the coating to the substrate.

One of the advantageous features of PLD is its ability to reproduce the composition of the target material in the grown layer. This enables the deposition of even complex, multicomponent materials. PLD can be described as a non-equilibrium and non-thermal process, as opposed to, for example, sputtering, thermal evaporation, and chemical vapor deposition methods. This gives PLD the ability to produce materials and artificial crystalline structures which could not be obtained using equilibrium methods and also multilayer structures and superlattices with well-defined, sharp interfaces.

In addition to vacuum conditions, PLD can be performed under almost any ambient gas. This gives us the opportunity to affect the composition of the coating in a reactive-PLD process or to change the dynamics of the ablated species leading to particle and cluster formation, which allows deposition of nanostructured layers. In addition to sensing applications, nano- and microstructured layers find use, for example, in photonic, photovoltaic, and catalytic applications.

Picodeon Series4 semi-industrial automated PLD system

Because of its versatility and flexibility, the PLD process is being applied to a wide range of material growth of both thin (single atomic layers) and thick (over 100 µm) films for an ever growing number of applications such as optics, electronics and semiconductors, tribological coatings, and biomedical coatings, to name just a few. However, apart from a few exceptions in the field of commercial fabrication, the applications of PLD are still at laboratory level in research and development.

PLD has mostly been done by using lasers with nanosecond pulse lengths. Today, more and more research is also being done concerning PLD with ultra-short pulsed lasers, covering femto- and picosecond regimes. The nanosecond PLD process is especially excellent for the deposition of high quality heteroepitaxial thin films and metamaterial superlattices of metal oxides, whereas ultra-short PLD (USPLD) is very suitable for deposition of metals and polycrystalline structures.

Picodeon Ltd Oy has been developing technology around ultra-short pulsed laser deposition with the goal of bringing PLD from the laboratory to commercial fabrication. This means that the process is designed to be capable for industrial production in terms of processing speed and the size and surface area of the products to be coated without compromising the quality and uniformity of the coatings. Currently, Picodeon's applications development includes coatings for sensors and batteries as well as tribological coatings.

Ville Kekkonen, M.Sc. (tech), works as a PLD Technologist at Picodeon being involved in the research and development activities in the company. He has been working with pulsed laser deposition since 2004. In the SENSIndoor project, he is responsible for the PLD process and development of the sensing layers.

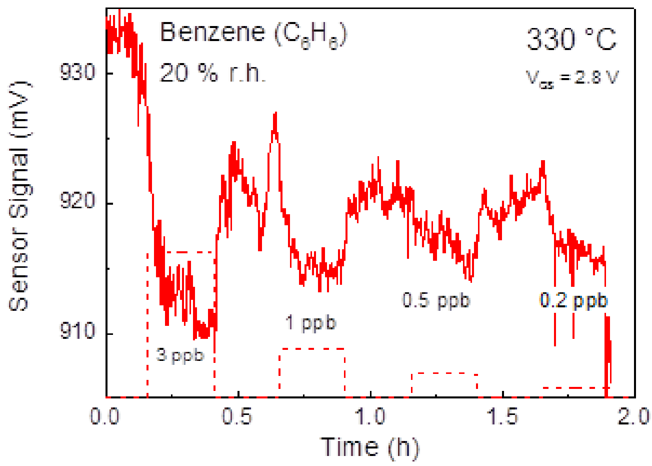
Jyrki Lappalainen is Professor of Electronics Manufacturing Technologies in the Microelectronics and Materials Physics Laboratories at the University of Oulu, Finland. He received his M.Sc. and PhD degrees in microelectronics and materials physics from the University of Oulu in 1993 and 2000, respectively. His research interests are in the field of nanostructured functional electroceramics.

Joni Huotari received his M.Sc. degree in electrical engineering from the Microelectronics and Material Physics Laboratories at the University of Oulu in 2010 and started as a PhD student in 2011. His primary research interest is the fabrication and characterization of functional materials for chemical sensors.

Smart solutions for better indoor air quality using silicon carbide field effect transistors

By Anita Lloyd Spetz and Donatella Puglisi (Linköping University, Sweden), Manuel Bastuck (Saarland University, Germany and Linköping University, Sweden), Mike Andersson (SenSiC and Linköping University, Sweden)

Field effect devices are highly favorable for gas sensing applications as they generally exhibit a logarithmic relationship between gas concentration and response

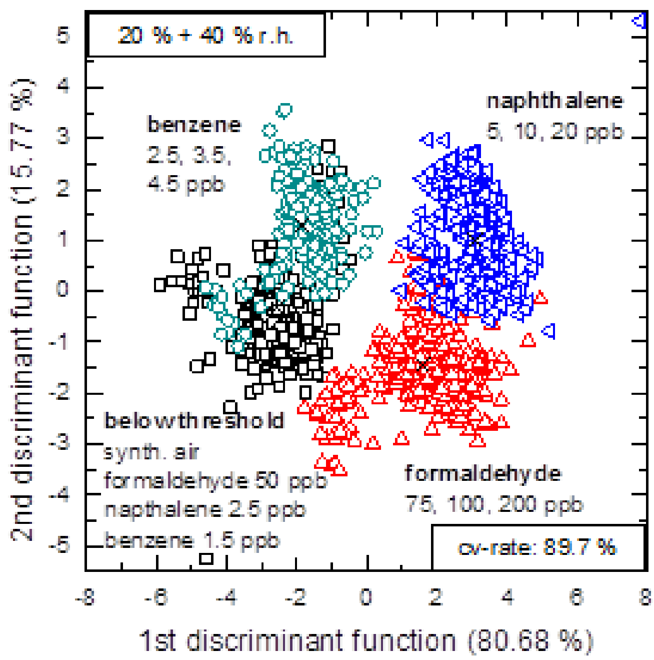


Sensor response to very low concentrations of benzene (C6H6) from 3 ppb to 0.2 ppb at 330 °C and 20 % relative humidity using a Ir-gated SiC-FET. (D. Puglisi et al., J. Sens. Sens. Syst., 4 (2015) 1-8)

(change in current/voltage) which is responsible for excellent sensitivity at ultra-low concentrations.

A single sensor unit can detect several gas molecules, depending on the working temperature and on the sensing material used for the gate contact. The choice of the sensing layer, together with smart operation – such as temperature or bias cycled operation – and advanced data evaluation based on multivariate statistics are two suitable approaches to enhance the device performance in terms of sensitivity and selectivity.

Within the SENSIndoor framework, the development of reliable and cost-efficient field effect transistors based on silicon carbide (SiC-FETs) for highly sensitive and selective detection of the three target VOCs, i.e. formaldehyde, benzene, and naphthalene, at the low parts per billion (ppb) down to sub-ppb concentration range is carried out as a collaboration between the following project partners: SenSiC AB and Linköping University, Sweden (development of the SiC-FET sensor platform and optimization of the sensing layer), University of Oulu and Picodeon LTD Oy, Finland (oxide materials for the gate contact processed by pulsed laser deposition technique), and Saarland University, Germany (smart operation and advanced data evaluation).

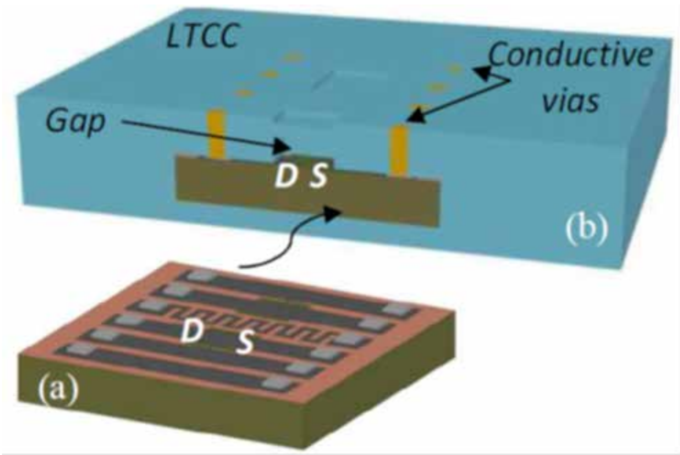


Discrimination of benzene (2.5, 3.5 and 4.5 ppb), naphthalene (5, 10, and 20 ppb), formaldehyde (75, 100, and 200 ppb) and carrier gas with combined relative humidity levels (20 % and 40% r.h.). (C. Bur et al., Sensor. Actuat. B-Chem. 214 (2015) 225-233).

In optimizing the sensor platform (the transistor) design regarding materials and thicknesses, including the introduction of device internal heating and operation temperature readout, sensor devices with generally increased sensitivity and signal to noise performance were developed. Catalytic metals, i.e., iridium (Ir) and platinum (Pt), and metal oxides, i.e., tungsten trioxide (WO_3) and vanadium pentaoxide (V_2O_5), were studied as sensing materials for the gate contact. The addition of a noble metal (Ir or Pt) to the metal oxide (e.g. WO_3) is also an effective means to enhance selectivity as these metal catalysts increase the rate of interaction differently for different gases. Until now, Ir-gated SiC-FETs have shown the highest performance in terms of sensitivity and long-term stability. Detection limits of 10 ppb for formaldehyde, 1 ppb for benzene, and below 0.5 ppb for naphthalene were demonstrated with Ir-gate SiC-FETs operating at 330°C and under 60% relative humidity. These results are very encouraging for indoor air quality control, being well below the threshold limits recommended by EU and US environmental agencies.

Discrimination of the three target VOCs, and quantification of naphthalene in the relevant concentration range, i.e. 0–40 ppb, were also performed. Hence, the suggested strategy is suitable for on demand ventilation control in indoor air quality application systems.

Increased performance may also be realized by the use of smart package solutions. The SiC-FET could be integrated in a Low Temperature co-fired Ceramic, LTCC module, in a one step process, whereby the sensor device is sintered together with the ceramics, the via materials and the printed leads, abolishing the need for separate die attachment, wire bonding and brazing to seal the package. The LTCC module may include means for gas collection and separation to further enhance the selectivity and sensitivity and also means for energy harvesting for autonomous sensors as well as control functions for realization of different applications.



Direct integration of SiC-based field effect sensor devices with the hermetic high temperature resilient LTCC package, the cross section giving an account of the sensor chip and conductive via locations.

Anita Lloyd Spetz is Professor and Head of the research division Applied Sensor Science at Linköping University (LiU), Sweden, and Finland Distinguished Professor, FiDiPro, at University of Oulu. She is LiU-team leader in SENSIndoor, Head of the VINN Excellence Centre FunMat at Linköping University, and Vice Chair for the COST Action TD1105 "European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability – EuNetAir". Her research at LiU involves SiC-FET high temperature gas sensors for harsh environment and gases like HC, NOx, CO, NH_3, H_2, SO_2 and volatile organic compounds, VOCs, transducers for biosensors, resonators, PM and graphene sensors, smart sensing and data evaluation, and at Oulu University a portable nanoparticle detector and a method for electrical detection of toxic effect of particles on cells.

Donatella Puglisi is Assistant Professor at the research division Applied Sensor Science, Linköping University (LiU), Sweden. She graduated in Physics at University of Catania, Italy, in 2005, and pursued her PhD in Physics from the same Institution in 2009. She worked (2009-2012) as a postdoctoral research fellow at Politecnico di Milano, in Como, Italy. She was hired as a post doc at Applied Sensor Science in October 2012. Her main research activities include development and characterization of gas sensitive field effect transistors based on silicon carbide (SiC-FETs) for detection of trace amounts of hazardous air pollutants for environmental monitoring and indoor air quality control. Puglisi is LiU-deputy team leader in SENSIndoor.

Manuel Bastuck received his M.Sc. in Microtechnology and Nanostructures from Saarland University, Germany, in 2014. He is currently enrolled in a joint PhD program between Saarland University and Linköping University, Sweden. His research involves optimization of gas sensor performance using cyclic operating modes and multivariate signal processing of the resulting data.

Mike Andersson is CTO at SenSiC and Associate Professor at Linköping University, Sweden. He finished his Ph.D. in Applied Physics at Linköping University in 2007. After two post doc years in a project with SKF R&D, Neuwegein, The Netherlands, around the direct integration of conditional sensors with ball bearings, he has been working as a project leader within the VINN Excellence Centre Functional Nanoscale Materials (FunMat) at Linköping University and as CTO of SenSiC AB for the development and commercialization of high temperature gas sensors. Since 2013, he has also been hired at the University of Oulu for a project on the development of high temperature LTCC based packaging of high temperature electronics and sensors. He has also participated in a number of European projects, including SENSIndoor, as project leader from SenSiC.

Metal oxide semiconductor gas sensors, pre-concentrators and integrated micro systems

By Martin Leidinger and Tilman Sauerwald (Saarland University, Germany), Christine Alépée (SGX Sensortech, Switzerland),Max Rieger (Fraunhofer Institute for Chemical Technology, Germany)

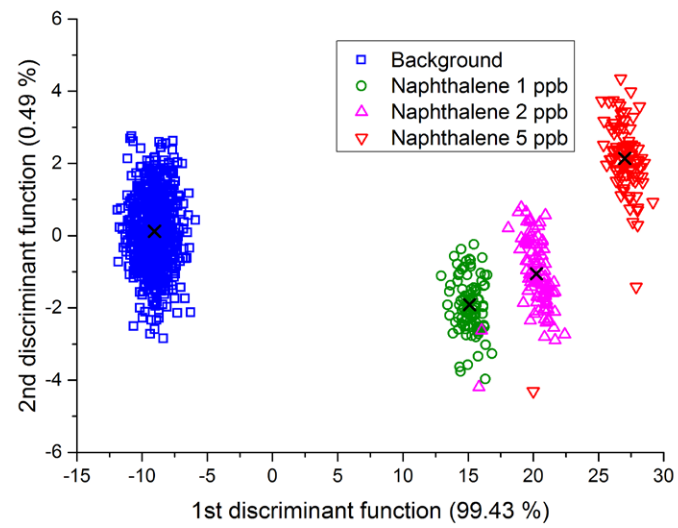
MOS gas sensors

The PLD layers developed in the SENSIndoor project have been deposited on SGX micro heater platforms, to produce gas sensors with low thermal time constants for fast temperature cycling of the devices. A variety of layers has been produced and characterized, the materials were tungsten trioxide (WO_3), tin dioxide (SnO_2) and tin dioxide in combination with zinc oxide (SnO_2/ZnO), all both undoped and doped with platinum (Pt). The materials were found to be sensitive to the SENSIndoor target gases, especially some of the WO_3 sensor types to naphthalene. Using a pure WO_3 sensor deposited at 0.2 mbar O_2 partial pressure in temperature cycled operation, naphthalene could be detected and quantified with high success rates in the concentration range of 1 ppb to 5 ppb.

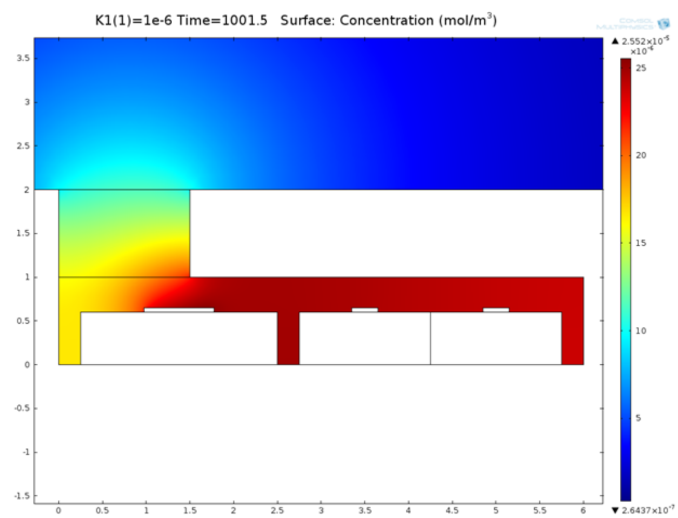
Pre-concentrators

In order to be able to reliably detect trace target compound concentrations, gas pre-concentration can be applied. Using a suitable material with a high surface area, gases can be collected over a certain period of time and then thermally desorbed, which generates a short pulse of high gas concentration.

As pre-concentrator materials, metal-organic frameworks (MOFs) have been chosen. These materials have a very high surface area (in some cases more than 1000 m^2/g), which means relatively large quantities of gas can be adsorbed and stored in a small volume of the material. In our investigation, two types of MOFs have been characterized regarding their benzene adsorption potential at room temperature and their desorption characteristics at elevated temperature. The two commercially available so-called Basolites®, A100 or MIL-53, and C300 or HKUST-1 were tested in comparison with a standard adsorbent (Tenax® TA in 60-80). The suitability of the metal-organic framework materials has been tested via invers gas chromatography measurements for adsorption and mass spectrometry measurements for desorption. Using iGC, relative affinities of benzene towards MOFs and a state-of-the-art adsorbent (Tenax® TA) could be determined. The MOFs outperformed Tenax® in this setup, which shows/proves they are suitable for pre-concentrating benzene.



Result of linear discriminant analysis (LDA) for discrimination of different naphthalene concentrations using a PLD WO3 sensor



Gas concentration after thermal desorption of the pre-concentrator (left); the highest gas concentrations are achieved in the gas sensors (right)

Integrated systems

Pre-concentrator chips with the MOF material deposited on a micro hot plate have been integrated into a ceramic SMD package next to a commercial SGX dual gas sensor. The geometry of the setup was also implemented into COMSOL Multiphysics for FEM simulations of the behavior of the system regarding gas diffusion and adsorption / desorption of gas at the pre-concentrator. In the simulations, the initial gas concentration could be increased by a factor of 11 to 32, depending on the simulated parameters. With the integrated system, test gas measurements for benzene pre-concentration have been successfully performed. For 10 ppb of benzene, with pre-concentration, the sensor signal was nearly as high as for 100 ppb without pre-concentration.

Martin Leidinger studied mechatronics engineering at Saarland University, Germany where he is now pursuing his PhD. His research interests are in design, operation and characterization of sensor systems for indoor air quality. In SENSIndoor, he evaluates the performance of the PLD MOS gas sensors and gas sensor systems for trace gas concentrations. He is also involved in the design, simulation and characterization of the integrated pre-concentrator / gas sensor microsystems.

Tilman Sauerwald received his PhD in 2007 at the University of Giessen, Germany working on the influence of surface reactions to the multi-signal generation of metal oxide sensors. Subsequently he worked in the field of nanostructured sensor material and bio-inspired sensor systems. Since 2011 he has been working at the Lab of Measurement Technology at Saarland University. His current focus is the detection of trace gases and the automated monitoring of the sensor integrity by developing model based techniques for multi-signal generation.

Christine Alépée studied micro-engineering and received her PhD from the Swiss Federal Institute of Technology in Lausanne in 2000. She joined MiCS/SGX in 2001 where she has focused her activities on the development of gas sensing MEMS based on various gas detection principles with the goal of improving commercial gas sensors in terms of sensing properties, power consumption, reliability and fabrication costs.

Max Rieger studied chemistry at the University of Würzburg, Germany and graduated in 2011. He is currently working on his PhD within the analytics and sensor group at the Energetic Materials department of the Institute for Chemical Technology (ICT). His thesis is mainly focused on utilizing metal organic frameworks as molecular selective sensor coatings and pre-concentrator material.

Commercial application areas for highly sophisticated IAQ sensors

By Wolfhard Reimringer and Thorsten Conrad (3S – Sensors, Signal processing, System GmbH, Germany), Olivier Martimort (NanoSense, France)

Assessing Indoor Air Quality (IAQ) is primarily about human health and comfort against the backdrop of energy consumption. Whereas in old houses the single biggest problem is keeping the right temperature and everything else is more or less well regulated by uncontrolled air exchange, modern buildings are built to be as energy efficient as possible – which comes along with air tight insulation and controlled ventilation. Operation of this kind of building means a compromise between no ventilation (optimal energy efficiency) and constant maximum ventilation (best air quality). On demand ventilation systems are equipped with various types of sensors to make this compromise.

From an economic point of view, the simplest and most cost effective setup is the best solution. Additional investment in special sensors can only be justified by substantially lowered running costs. However, air quality can only be improved in the scope of known parameters: Traditionally, humidity, CO_2 concentration and human presence are considered to be linked. This implies that the respective sensors can be used interchangeably too – which rules out expensive NDIR CO_2 cells for the sake of cheap humidity sensors or PIR occupancy detectors.

However, this approach has to be treated with caution as it apparently includes strong simplification. There may be situations where this simplification is permissible but oftentimes it is not. For instance, during wintertime background air is very dry and humidity increase by human breathing becomes insignificant. Also, PIR sensors are unable to count the number of persons and the corresponding CO_2 generated. Searching for application areas for highly sophisticated IAQ sensor systems means identifying conditions under which this deduction is not valid.

A hint for breaking the link between air quality and human presence can be derived from situations when air quality is compromised in the absence of occupants: Excess humidity from domestic processes (such as cooking, washing, cleaning) as well as gaseous components from building materials and furniture are striking examples. Whereas humidity controlled ventilation for kitchens, bathrooms and housekeeping areas are state-of-the-art, other gaseous components are seldom assessed for IAQ appropriately. Commercially available solutions give an estimate of the total concentration of Volatile Organic Compounds (VOCs) but are inherently unspecific to their composition.

The need for composition identification can be illustrated by two examples: One is odor assessment where the smell of a freshly cleaned place should not increase ventilation level in contrast to off-smells from burned food or a lavatory. A more serious application is the discrimination of hazardous components as formaldehyde, naphthalene and benzene against VOCs which are not that health sensitive like perspiration (valeric acid under smelling threshold), ethanol or perfumes. The challenge is to identify hazardous substances at very low concentration levels in the presence of much higher concentrated, non-hazardous interferents.

While odor assessment is a mere comfort feature which can be consequently marketed to a solvent group of customers, hazardous VOC identification could be seen as a technical necessity which has to be paid for. Willingness to invest in selective VOC measurement has to be fostered in contexts that include those in special need of protection: Hospitals, elderly homes and – most strikingly – children's care from cribs and nurseries to schools. Public responsibility and expectation, good image and legal regulation are key terms in this market.

A ready-to-use implementation of SENSIndoor technology will have to include long-term stability and accuracy of the measurement as well as an easy to install, easy to maintain, commercially available device that interfaces with the relevant infrastructure. While KNX connection is a good start for new buildings, some effort will have to be added to access existing installations – EnOcean and Thread devices powered by energy harvesting are just one example.

Beyond the objective of SENSIndoor, there are manifold applications for advanced air quality sensor systems: In refrigerators, bacteria growth on fish generates specific VOCs (putrescine, cadaverine and indole), detection of which far under smelling threshold can warn the user to prevent intoxication. Used in extractor hoods, unhealthy overcooking can be prevented by detecting aldehyde and adjusting cooking temperature in addition to increased ventilation. Outdoor uses of sensitive and selective VOC sensor systems include emission monitoring as well as very specific tasks such as truffle hunting.

Wolfhard Reimringer studied electrical engineering and received his M.Sc. in from Saarland University of applied sciences, Saarbruecken, Germany in 2013. He first joined 3S as a developer for electronic hardware in 2009, subsequently taking over additional responsibilities in system integration and design as well as product management tasks for air quality applications. Already having designed the field test device used in the mnt-era.net project VOC-IDS he is designated work package leader for WP8 "Sensor system integration" in SENSIndoor.

Thorsten Conrad studied electrical engineering and received his diploma from Saarland University in 2002. From 2003-2007, he worked with various research institutes focusing on electronics and chemical sensors. He has been managing partner of 3S and, among other things, responsible for R&D project coordination and strategic business development.

Olivier Martimort is a senior engineer in electronics and has been involved in the only French contribution to the US Strategic Defence Initiative (SDI). He set up NanoSense in 2002 and is currently the company's CEO. He manages the R&D department and is personally involved in each project.

Interfacing Activities

By Corinna Hahn (Eurice)

The SENSIndoor project represents a truly European initiative. The project partners are closely linked to a wider community of established universities and research institutes as well as innovative companies in the field. Collaborations exist at different levels and with different foci. The EuNetAir COST Action offers networking opportunities and also represents a forum for SENSIndoor partners to disseminate and discuss their results. In addition, the partners use this excellent platform to identify promising ideas and partners for new initiatives.

A closer cooperation has been established with the IAQSense project, which resulted from the same EU call as SENSIindoor and also deals with the development of innovative systems to improve indoor air quality. IAQSense aims to develop new nano¬technology based sensor systems that will precisely monitor the composition of the air in terms of both chemical and bio contaminants. This system will be miniaturized, low cost and adapted to mass production.

A major challenge consists of a gas sensor system which must be at the same time low cost and highly sensitive and selective. IAQSense relies on three patented technologies, of which one is based on surface ion mobility dynamics separating each gas component. Working like a spectrometer it allows high sensitivity fast multi-gas detection in a way never seen before.

The Eurosensor 2015 conference in Freiburg, at which SENSindoor results were presented by several partners, see also separate info, represented a good opportunity to organize a meeting with the sister project IAQSense. Representatives of both projects met at the Intercity hotel in Freiburg on September 10, 2015. The aim of the meeting was to discuss the current status of as well as synergies between both projects. The meeting was attended and moderated by Eberhard Seitz, the PTA for both projects, as well as Hans-Hartmann Pedersen representing the European Commission.

Partners from SENSIndoor and IAQSens,together with EC representatives and the Project Technical Advisor at their meeting in Freiburg

The project partners have agreed on a common agenda which includes two main lines of activities. On the one hand, synergies at the scientific and technological levels will be explored by carrying out cross-comparison experiments. On the other hand, common dissemination activities are planned, such as the organisation of a common booth at a major fair as well as the organisation of a session at the Indoor Air conference in 2016. In addition, the two projects plan to elaborate a common strategy paper which focuses on standardization issues at the European level. The contents of the strategy paper will be aligned with the roadmapping activities of the ESSC cluster mentioned above.

Corinna Hahn is Senior Programme Manager at Eurice GmbH. She has over 15 years of experience in EC funded projects, with a particular focus on technical sciences, energy and climate. In SENSIndoor, Corinna Hahn leads the work package on dissemination and exploitation of project outcomes, which includes, among other things, interfacing with sister projects and networks, awareness raising and common actions.

Key Publications

Pulsed Laser Deposition Technology

Pulsed Laser Depositon of Metal Oxide Nanoparticles, Agglomerates, and Nanotrees for Chemical Sensors

J. Huotari, J. Lappalainen, J. Puustinen, T. Baur, C. Alépée, T. Happalainen, S. Komulainen, J. Pylvänäinen, A. Lloyd Spetz

Procedia Engineering 120 (2015), 1158 – 1161 DOI: 10.1016/j.proeng.2015.08.745

Abstract: Pulsed Laser Deposition (PLD) was used to prepare WO_3, ZnO-modified SnO_2, and V_2O_5 nanostructures as gas sensing materials on top of commercial SGX Sensortech MEMS microheater platforms. The layers were formed of different types of nanostructures including nanoparticles, agglomerates, and nanotrees with fractal-like growth. Clear dependency between the deposition parameters, structural morphology, and gas sensing performance was found. The sensing materials were found to be sensitive to different types of gaseous species, so that WO3 and SnO_2 had very good response up to 600% to 50 ppm NO, and V_2O_5 up to 35% to 20 ppm NH_3, respectively.

MOS sensors for ppb level VOC

Selective detection of hazardous VOCs for indoor air quality applications using a virtual gas sensor array

M. Leidinger, T. Sauerwald, W. Reimringer, G. Ventura, A. Schütze

Journal of Sensors and Sensor Systems, 3 (2014), 253-263 DOI: 10.5194/jsss-3-253-2014

Abstract: An approach for detecting hazardous volatile organic compounds (VOCs) in ppb and sub-ppb concentrations is presented. Using three types of metal oxide semiconductor (MOS) gas sensors in temperature cycled operation, formaldehyde, benzene and naphthalene in trace concentrations, reflecting threshold limit values as proposed by the WHO and European national health institutions, are successfully identified against a variety ethanol background of up to 2 ppm. For signal processing, linear discriminant analysis is applied to single sensor data and sensor fusion data. Integrated field test sensor systems for monitoring of indoor air quality (IAQ) using the same types of gas sensors were characterized using the same gas measurement setup and data processing. Performance of the system is reduced to gas emissions from the hardware components. These contaminations have been investigated using analytical methods. Despite the reduced sensitivity, concentrations of the target VOCs in the ppb range (100 ppb for formaldehyde; 5 ppb of benzene; 20 ppb of naphthalene) are still clearly detectable with the systems, especially when using the sensor fusion method for combining data of the different MOS sensor types.

SiC-FET sensors for ppb level VOC

Catalytic metal-gate field effect transistors based on SiC for indoor air quality control

D. Puglisi, J. Eriksson, C. Bur, A. Schütze, A. Lloyd Spetz, M. Andersson

Journal of Sensors and Sensor Systems, 4 (2015), 1-8 DOI: 10.5194/jsss-4-1-2015

Abstract: High temperature iridium-gated field effect transistors based on silicon carbide have been used for sensitive detection of specific volatile organic compounds (VOCs) in concentrations of health concern, for indoor air quality monitoring and control. Formaldehyde, naphthalene, and benzene were studied as hazardous VOCs at parts per billion (ppb) down to sub-ppb levels. The sensor performance and characteristics were investigated at a constant temperature of 330 °C and at different levels of relative humidity up to 60%, showing good stability and repeatability of the sensor response and excellent detection limits in the sub-ppb range.

Pre-Concentrators Using MOF

Trace gas VOC detection using metal-organic frameworks as preconcentrators and semiconductor gas sensors

M. Leidinger, M. Rieger, D. Weishaupt, T. Sauerwald, M. Nägele, J. Hürttlen, A. Schütze.

Procedia Engineering 120 (2015), 1042 – 1045
DOI: 10.1016/j.proeng.2015.08.179

Abstract: A method for the measurement of low gas concentrations is presented. The method was developed for detection of Volatile Organic Compounds (VOCs) in indoor air quality applications and tested with benzene, a carcinogenic VOC with no safe exposure limit value. Using metal organic framework materials, gas pre-concentration devices for benzene were prepared on ceramic micro hotplates and characterized. Two MOF materials (HKUST-1 and MIL-53) were tested. Both showed good preconcentrator performance concerning adsorpiton and desorption of the target gas. A significant temporary decrease of the benzene concentration in the sampling phase and a corresponding increase in the desorption phase were detected using a mass spectrometer. The MOF pre-concentrators were also tested in combination with a semiconductor gas sensor resulting in a significant increase in the sensor repsonse in the desoption phase.

Data Evaluation

Discrimination and quantification of volatile organic compounds in the ppb range with gas sensitive SiC-FETs using multivariate statistics.

C. Bur, M. Bastuck. D. Puglisi, A. Schütze, A. Lloyd Spetz, M. Andersson

Sensors and Actuators B: Chemical (2015),
DOI: 10.1016/j.snb.2015.03.016

Abstract: Gas sensitive FETs based on SiC have been studied for the discrimination and quantification of hazardous volatile organic compounds (VOCs) in the low ppb range. The sensor performance was increased by temperature cycled operation (TCO) and data evaluation based on multivariate statistics, here Linear Discriminant Analysis (LDA). Discrimination of formaldehyde, naphthalene and benzene with varying concentrations in the ppb range is demonstrated. In addition, it is shown that naphthalene can be quantified in the relevant concentration range independent of the relative humidity and against a high ethanol background. Hence, gas sensitive SiC-FETs are suitable sensors for determining indoor air quality.

PhD Thesis on SENSIndoor Research

Selectivity Enhancement of Gas Sensitive Field Effect Transistors by Dynamic Operation

C. Bur

Doctoral thesis, monograph, 2015, Linköping University and Saarland University
DOI: 10.3384/diss.diva-114670

Abstract: Gas sensitive field effect transistors based on silicon carbide, SiC-FETs, have been applied to various applications mainly in the area of exhaust and combustion monitoring. So far, these sensors have normally been operated at constant temperatures and adaptations to specific applications have been done by material and transducer platform optimization. In this thesis, the methodology of dynamic operation for selectivity enhancement is systematically developed for SiC-FETs. Temperature cycling, which is well known for metal oxide gas sensors, is transferred to SiC-FETs. Additionally, gate bias modulation is introduced increasing the performance further. The multi-dimensional sensor data are evaluated by use of pattern recognition mainly based on multivariate statistics. Different strategies for feature selection, crossvalidation, and classification methods are studied.

After developing the methodology of dynamic operation, i.e., applying the virtual multi-sensor approach on SiC-FETs, the concept is validated by two different case

studies under laboratory conditions: Discrimination of typical exhaust gases and quantification of nitrogen oxides in a varying background is presented. Additionally, discrimination and quantification of volatile organic compounds in the low parts-perbillion range for indoor air quality applications is demonstrated. The selectivity of SiC-FETs is enhanced further by combining temperature and gate bias cycled operation. Stability is increased by extended training.

Christian Bur was a member of the SENSIndoor group at USAAR until 2015. He received an award for his PhD thesis from the AHMT, the German Association of Metrology Professors, for his significant contribution to the advancement of measurement science and technology. Christian Bur's thesis was written and accepted at both Saarland University and Linköping University under the DocMASE program.

A full list of publications is available on www.sensindoor.eu.

Upcoming events

Air Quality 2016

March 14-18, 2016, Milan, Italy

The conference will focus on air quality research and its applications. Key issues are achieving sustainable development and reducing health impacts in all regions of the world.

More information

18. GMA/ITG Fachtagung Sensoren und Messsysteme 2016

May 11-12, 2016, Nuremberg, Germany

The symposium "Sensoren und Messsysteme", held together with SENSOR+TEST 2016, is the most prominent German-speaking scientific symposium for measurement technology.

More information

SENSOR+TEST 2016 The Measurement Fair

SENSOR+TEST 2016
DIE MESSTECHNIK-MESSE
The Measurement Fair
Nürnberg, Germany
10. – 12.5.2016

May 10-12, 2016, Nuremberg, Germany

SENSOR+TEST is one of the major international scientific forums for professionals in the fields of measuring, testing and monitoring from various industries. This trade fair offers exhibitions covering the complete spectrum from sensors to evaluation.

More information

Air Pollution 2016

June 20-22, 2016, Crete, Greece

The 24th International Conference on Modelling, Monitoring and Management of Air Pollution addresses a wide range of issues and challenges in the field of outdoor as well as indoor air pollution. The conference brings together experts who share the newest findings from science and policy/decision makers.

More information

E-MRS Spring Meeting 2016

May 2-6, 2016, Lille, France

The 2016 Spring Meeting of the European Materials Research Society (E-MRS) is the largest event in Europe in the field of Materials Science and Technology. The scientific programme will include 31 parallel symposia focusing on a wide spectrum of topics related to fundamental investigations as well as technological applications in the hottest fields of materials science.

Special COST Action EuNetAir Session

The COST Action TD1105, EuNetAir, will hold Symposium X at the E-MRS Spring Meeting 2016, titled „Functional materials for environmental sensors and energy systems“.

More information

2nd International Conference on Functional Integrated nano Systems (nanoFIS)

June 27-29, 2016, Graz, Austria

The 2016 nanoFIS Conference focuses on the implementation of Key Enabling Technologies for Novel Device Development and 3D System Integration. The conference is organized by the Materials Center Leoben Forschung GmbH (MCL), a leading research company in Austria. The conference will focus on 5 main topics: Advanced functional materials, nanosensors, system integration and packaging, reliability and innovative manufacturing processes.

More information

Indoor Air 2016

July 3-8, 2016, Ghent, Belgium

The 14th International Conference on Indoor Air Quality and Climate is a flagship conference in the broad field of indoor air sciences including sensor technology for monitoring indoor air quality. The multidisciplinary programme focuses on a wide variety of topics such as building ventilation, energy efficient buildings, new materials, prediction and measurement.

Special SENSIndoor/IAQSense Session

SENSIndoor will hold a special session at Indoor Air 2016. The session with the title C*hanging the game in the management of Indoor Air Quality – Real time monitoring for improved health, comfort and energy-efficiency* aims at increasing the awareness of novel low-cost sensor solutions for Indoor Air Quality, especially for Volatile Organic Compounds (VOCs) and at providing ubiquitous sensor systems as key components for demand controlled ventillation. In the session, leading experts in Indoor Air Quality will introduce and, together with the audience, discuss key contaminants relevant for indoor air quality assessment as well as solutions to their reduction. Special emphasis is placed on new developments for VOC sensors developed within SENSIndoor and its partner project IAQSense and on their impact on Indoor Air Quality monitoring and improvement to achieve the goal of healthy and green buildings with greatly reduced energy consumption.

More information

IMCS 2016

July 10-13, 2016, Jeju, Jeju Island, Korea

The 16th International Meeting on Chemical Sensors is a large interdisciplinary forum covering all aspects of chemical sensors such as physics, chemistry, electronics and materials together with engineering disciplines. The 2016 event offers a wide variety of topics, among them emerging sensing technologies, nanomaterials for chemical sensors, sensor systems and manufacturing, sensing for health, safety and security and many more.

More information

Eurosensors 2016

September 4-9, 2016, Budapest, Hungary

The 30th edition of the Eurosensors Conference will present latest results on, among other things, micro and nanosystems, packaging interface and system integration, emerging sensor technologies and sensor application areas. A strong focus lies on the innovative nature of research to be presented.

More information

IEEE Sensors 2016

October 30 - November 1, 2016, Orlando, Florida

IEEE Sensors 2016 is intended as a forum for international research scientists, engineers, and practitioners to present their latest findings, ideas, and applications in the area of sensors and sensing technology. Topics of interest include Chemical and Gas Sensors as well as Materials and many more.

Plans for a dedicated SENSIndoor session at this conference are currently under way.

More information

Electronica 2016

November 8-11, 2016, Munich, Germany

Electronica, the bi-annual International Trade Fair for Electronic Components, Systems and Applications, showcases the electronics industry's full range of technologies, trends, products and solutions. Moreover, the trade fair is a global platform for investors, ensuring first-rate potential for new business. Special theme-oriented forums facilitate exchange on the level of science and networking.

More information

Consortium Members

Lab for Measurement Technology, Saarland University (USAAR), Germany
Prof. Andreas Schütze (Coordinator), Dr. Tilman Sauerwald, Martin Leidinger, Manuel Bastuck (USAAR/LiU joint PhD student), Dr. Christian Bur (until 2015)
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SENSIndoor Fact Sheet

Full Title
Nanotechnology-based intelligent mutli SENsor System with selective pre-concentration for Indoor air quality control

Programme
7th Framework Programme of the European Commission – NMP – Small or Medium-sized Collaborative Projects

Duration
36 months (start date: January 2014)

Project Funding
3.399.995,00 €

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