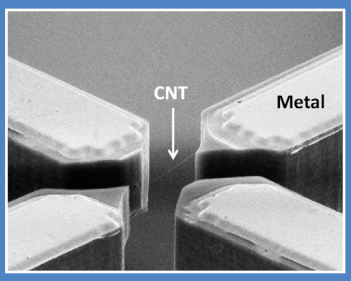
# CabTuRes

## ENABLING AUTONOMOUS SENSOR NODES: LOW-POWER NANO-SENSOR/ELECTRONICS BUILDING BLOCKS BASED ON TUNABLE CARBON NANOTUBE ELECTRO-MECHANICAL RESONATORS

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Dr. Danick Briand, EPFL


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### What it's about…

***Developing nano-mechanical resonators for sensing and electronics applications***

### Context and project goals

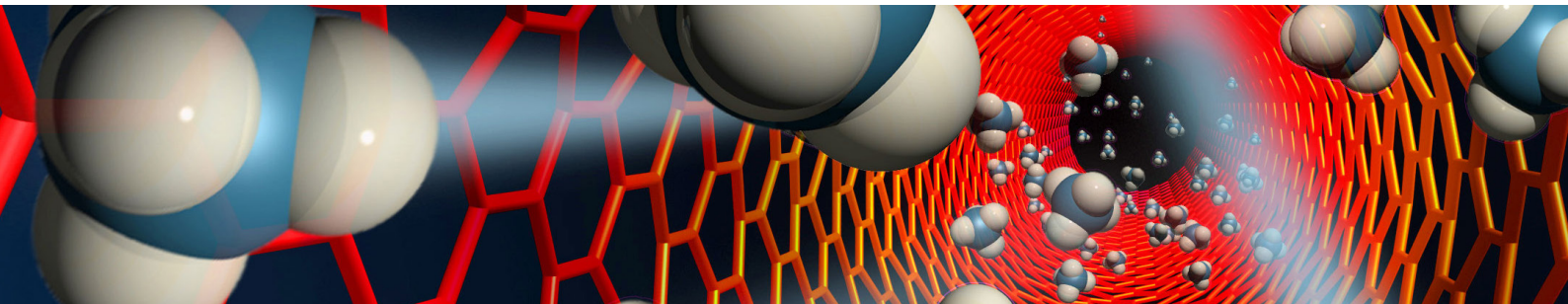
The project's goal was to demonstrate concepts and devices for ultra-low power, highly miniaturized functional blocks for sensing and electronics. At the core are carbon nanotube mechanical resonators, which can be tuned via straining over a wide frequency range, offer an unprecedented sensitivity to strain or mass loading, and all these with a very low power consumption.

### How the project differentiates from similar competition in the field

While several research groups worldwide are currently investigating tunable carbon nanotube resonators, CabTuRes distinguishes in its objectives by including fabrication and system integration aspects. System integration is a core task aiming at proving the feasibility of assembling the resonators with interface electronics.

### Quick summary of the project status and key results

CabTuRes has advanced the international state-of-the-art at both the fundamental and technological levels. Regarding technology, processes for growing CNTs with excellent control over location, growth yield and directionality have been demonstrated. Two processes suitable for batch fabrication of CNT resonators have been developed; one focusing on tubes with close-by gates without mechanical straining option; the other focusing on tubes with mechanical actuators for frequency tuning. Tunable CNT resonators have been fabricated and frequency and Q-factor tuning has been demonstrated. Several key blocks of the interface electronics have been designed and characterized, such as a low noise front-end amplifier to interface the CNT devices and a CMOS IC for closed-loop operation of resonators and tested with a CNT emulator. A system integration and packaging process has been defined and most of its critical unit processes—including RF-compatible, ohmic Trough-Silicon-Vias, glass-cap encapsulation and CMOS IC stud-bump soldering—have been developed and tested. At the basic level, the team has investigated adsorption of different chemical species on CNTs and the mechanical interface between CNTs and their anchors.



## Success stories

### Key scientific results

Localized CNT growth with one tube per catalyst particle, yielding ultra-high mobility CNT transistors • Identification of NOX sensing mechanism with NO3 adsorption on SWNTs via electrostatic interactions • CNT resonator integration with increased device yield • Demonstration of 2ω piezoresistive currents in electrostatically strained CNTs for improved readout of resonating tubes • Frequency and Q-factor tuning (Q=184) by mechanical actuation with integrated MEMS thermal actuators • Temperature-compatible RF TSVs for 3D integration.

### Awards

Matthias Muoth, Kiran Chikkadi and Yu Liu won the Outstanding Poster Paper Award at IEEE MEMS 2013 for the paper "Suspended CNT-FET Piezoresistive Strain Gauges: Chirality Assignment And Quantitative Analysis"

Christian Kauth, Marc Pastre, Maher Kayal "Poland section IEEE ED chapter award", for the paper entitled "Closed-Loop Oscillator Circuit for Piezoresistive Carbon Nanotube NEMS Resonators", Mixed Design of Integrated Circuits and Systems conference, Poland/Gdynia, June 2013

### Presence in the media

"Nowadays, nanoresearch is routine" ETH Globe, No. 2. June 2013. (http://www.ethz.ch/about/publications/globe/archive/globe_2_2013_nano_EN.pdf)

### Main publications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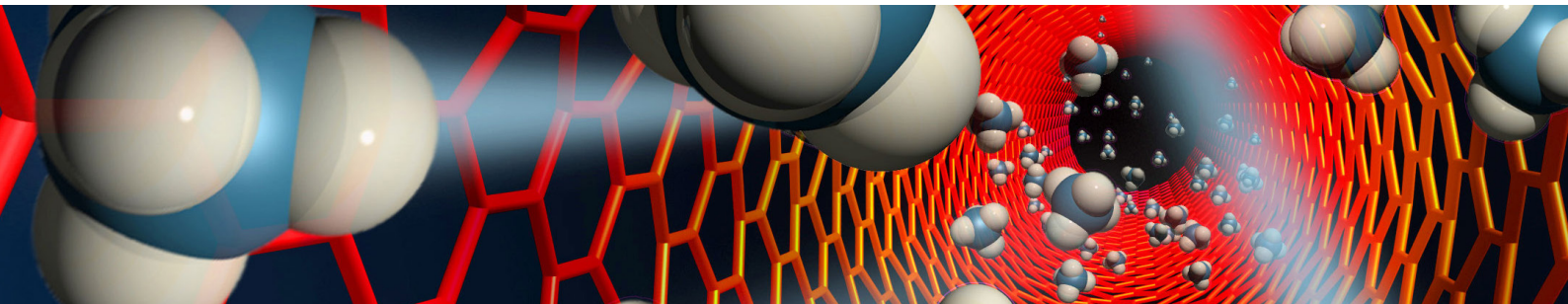
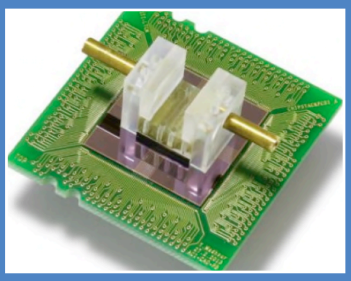


Prof. John Thome, EPFL

# CMOSAIC

## 3D STACKED ARCHITECTURES WITH INTERLAYER COOLING



Prof. David Atienza, EPFL

Prof. Yusuf Leblebici, EPFL

Dr. Bruno Michel, IBM ZRL

Prof. Dimos Poulikakos, ETHZ

Prof. Wendelin Stark, ETHZ

**What it's about…**

***Designing multi-layered computer chips with interlayer cooling for increased computing performance and reduced energy consumption***

**Context and project goals**

The project addresses interlayer cooling of 3D computer chips, including water cooling, two-phase refrigerant cooling, development and perfection of new micro-fabrication techniques for TSVs and their connections, bonding of stacked layers together, dynamic thermal modeling of 3D chips, and extensive experimental testing of 2D and 3D cooling solutions and new thermal models.

**How the project differentiates from similar competition in the field**

Other labs are not as advanced in the thermal modeling of the underlying heat transfer processes nor in the manufacturing and testing of 3D test vehicles.

**Quick summary of the project status and key results**

CMOSAIC has combined the most advanced microscale heat transfer experiments and modeling with the most advanced 3D manufacturing developments, thus building the most convincing 3D test vehicles to date on the 3D-IC roadmap for development of the next generation of high performance computing within 3D architectures the size of a sugar cube cooled with microchannels. The teamwork has produced final 3D test vehicles which have four-thousand TSV's inside connected to numerous local heaters and resistance thermometers. The packaging of this 3D vehicle not only allows the flow of electricity through the device but also the flow of coolant though all its layers for the removal of large heat densities. This is combined with the development of the most advanced 3D thermal simulation codes now available for both single-phase cooling and two-phase cooling, including both very fast simulators for rapid analysis and a very detailed simulator with the first ever combined heat and two-phase flow spreading capabilities.

## Success stories

### Awards

Outstanding Paper Award, ICEPT HDP 2012 Conference (International Conference on Electronic Packaging Technology and High Density Packaging) for the following paper: Madhour, Y., Brunschwiler, T., El Kazzi, M., Thome, J.R., Michel, B., "Patterned die-to-die thin film bonding for 3D chip stacks with integrated microfluidic cooling", International Conference on Electronic Packaging Technology and High Density Packaging, 2012. The award ceremony took place at this year's ICEPT-HDP 2013 conference. The prize was awarded for a concept for a scalable integrated cooling technique that requires a novel die-to-die solder bonding method. The bonding method they designed and successfully tested exploits patterned thin-film lead-free solder and meets the challenges posed by integrating state-of-the-art cooling structures into a 3D chip stack, such as minimizing the gap between the dies, sealing the active solder pads from a conductive coolant fluid, and sealing the edges of the chip to prevent leakage.

### Production of the final CMOSAIC package demonstrating packaging and cooling technologies for future interlayer cooled 3D chip stacks:

The package consists of five 380µm-thick 12.7x12.7 mm2 silicon chips flip-chip bonded to form the chip stack. These chips represent mock-ups of real devices, with controlled resistive heaters acting as processor cores and embedded microchannels on the back for integrated cooling. The reason why the consortium considers the packaging/interlayer cooling technologies developed in CMOSAIC as a success story is because they demonstrate the feasibility at an early stage of industrial development. The availability of such demonstrators helps to accelerate the development of the industry towards this new direction.

### Main publications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M. Sabry, J.L. Ayala, D. Atienza, Thermal-Aware Compilation for Register Window-Based Embedded Processors, Embedded Systems Letters, IEEE Press, ISSN: 1943-0663, Vol.2, Issue/Nr. 4, pp. 103-106, DOI: 10.1109/LES.2010.2081343, December 2010.

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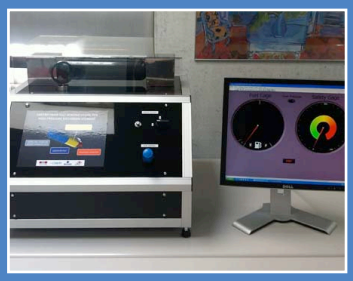
Prof. Jan-Anders Månson, EPFL

# GreenPower

## CONNECTING RENEWABLE ENERGY TO GREEN MOBILITY USING HYDROGEN AS ENERGY CARRIER UNDER THE BELENOS CLEAN POWER INITIATIVE



Dr. Emmanual Onillon, CSEM

Dr. Lorenz Gubler, PSI

### What it's about…

***Demonstrating a Swiss technology for hydrogen mobility with optimization of the overall energy flow and focus on hydrogen storage and use in a fuel cell.***

### Context and project goals

The use of $H_2$ based on renewable resources to substitute fossil fuels for mobility and stationary applications is key to reduce $CO_2$ emissions. The challenges targeted by the project are cost reduction and enhanced safety, primarily for i) $H_2$ storage under high pressure through the development of polymer composite vessels with unique self-sensing liners and ii) use in fuel cells with novel grafted polymer membranes.

### How the project differentiates from similar competition in the field

The polymer membranes for the fuel cell are less expensive and more durable than commercial membranes thanks to a novel radiation grafting chemistry. The polymer composite hydrogen storage vessels include for the first time a self-sensing piezoelectric 'liner' and are produced using a cost-effective fiber weaving technology. The optimization of the energy system includes all process steps (production, storage, use).

### Quick summary of the project status and key results

In 2013 *proton-exchange membranes* (PEM) were produced with superior durability compared to commercial PEM. A demonstrator of a *self-sensing composite vessel* for high pressure storage was produced, including a novel liner material with outstanding combination of gas-barrier and piezoelectric properties. The *energy flow optimization* was implemented on the associated user's interface and methods were studied for fuel cell health monitoring. *Belenos car and boat demonstrators* accomplished one year test under real drive and navigation conditions.

## Success stories

- L'Agefi "Swatch: projet de véhicule à hydrogen et oxygène" (26.03.2012)
- Tribune de Genève « Swatch n'a pas renoncé à sa voiture propre » (26.03.2012)
- Le Matin « A quand une Belenos à 18 000 francs ? » (26.03.2012)
- 20 Minuti Ticino « La Swatch (ri)pensa a un'auto » (26.03.2012)
- RTS « Swatch veut développer une voiture écologique » (25.03.2012)
- Romandie.com « Swatch envisage de fabriquer une voiture écologique » (25.03.2012)
- Finanzen.ch « Hayek entwickelt das Auto der Zukunft » (25.03.2012)
- Handelszeitung.ch « Hayek entwickelt das Auto der Zukunft » (25.03.2012)
- Search.ch « Swatch envisage une voiture verte » (25.03.2012)
- Touring « La Suisse contribue au futur de l'auto » (19.05.2011)
- Environnement « Mobilté du futur : entre science-fiction et réalité » (01.09.2012)

**Proton exchange membranes (PEM)**. Commercialization of polymer electrolyte fuel cell technology calls for components that yield high performance and durability at low cost. Commercial perfluorinated membranes (e.g., Nafion®) are associated with high production cost. Radiation grafted membranes, such as the one developed at PSI, offers the prospect of reduced cost by a factor of 2 to 5, under ideal conditions by a factor of 10. In the course of the Nano-Tera Greenpower project, the following technological achievements were accomplished:

- Scale-up of membrane fabrication in the lab to a batch size equivalent to a fuel cell stack of 3.5 kW
- Fuel cell performance equivalent to commercial benchmark
- Durability exceeding that of state-of-the art membranes under dynamic operating conditions.

**Piezoelectric gas barrier liner.** The collaboration between EPFL and CSEM on the analysis of a P(VDF-TrFE) copolymer was instrumental to elucidate the transformation of the paraelectric crystalline phase into the polar β-phase upon annealing between the Curie temperature and the melting point. This thermal process enhanced the proportion of β-phase up to 95%, leading to a remarkable 10-fold decrease of $O_2$ permeability and 40% increase in the piezoelectric coefficient d33.

### Main publications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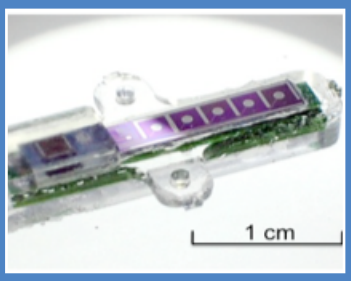
Prof. Giovanni De Micheli, EPFL

# i-IronIC

## IMPLANTABLE/WEARABLE SYSTEM FOR ON-LINE MONITORING OF HUMAN METABOLIC CONDITIONS




Dr. Sandro Carrara, EPFL

Dr. Catherine Dehollain, EPFL

Dr. Fabio Grassi, IRB

Prof. Qiuting Huang, ETHZ

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Dr. Linda Thoeny-Meyer, EMPA

**What it's about…**

***Building a prototype of a human implant to detect various markers of diseases and supporting remote monitoring.***

**Context and project goals**

The project goals were to develop a fully implantable sensors system, involving multi-panel sensors capable to sense several metabolites, all in parallel, in real-time and CMOS design for the fully-implanted, complex, and low-consumption electronics for sensing and remote powering.

**How the project differentiates from similar competition in the field**

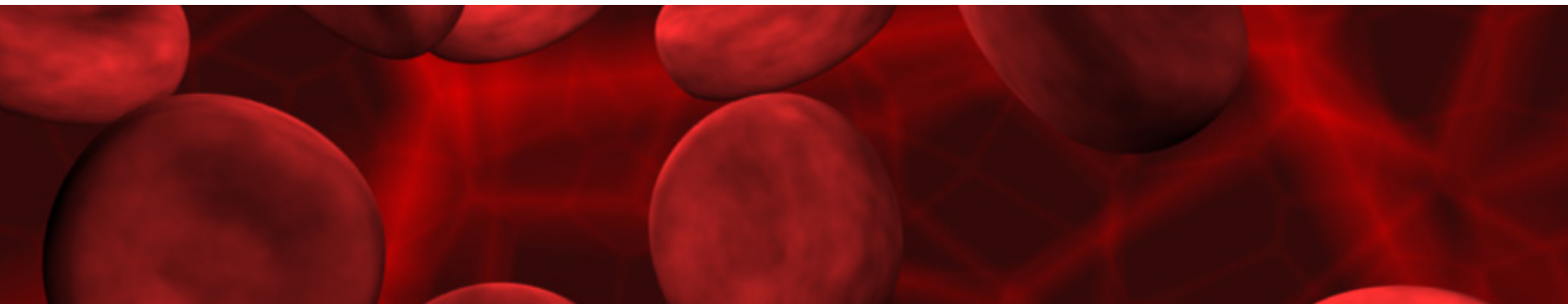
- The smallest multi-panel fully implantable biochip ever built
- A deep integration of bio and nano-materials onto micro-fabricated platform for multi-target sensing
- The development of an intelligent patch to be located on top of the skin for remote powering of the implant and data transition to a smart-phone.

**Quick summary of the project status and key results**

- The smallest multi-panel fully implantable biochip
- Biocompatible packaging for the implantable biochip
- The intelligent patch for remote powering
- Detection of some non-commonly detected metabolites (e.g., the ATP)
- Design of a very tiny (1.5x1.5 $mm^2$) integrated circuit CMOS frontend for the nano-bio-sensor

**Patent**

Irene Taurino, Magrez Arnaud, Forro Laszlo, Giovanni De Micheli, Sandro Carrara: Close and Selective Integration of Carbon Nanomaterials by CVD onto working microelectrodes of multi sensing electrochemical biosensors, filed at the European Patent Office on September 13th 2013, registration # EP 13184291.6.



## Success stories

One of the industrial partners (Menarini Diagnostics) asked the team to push the technology set during this project for applications on intensive care units. A new proposal has been written following this request and the project has been funded. The new project phase under this new grant started in late 2013. Another successful story is the deep and intimate integration of Carbon nanotubes in a selective manner on multi-panel platforms that succeeded in getting a new patent and a top-publication in the Royal Society Journal Nanoscale (Impact Factor > 6).

**Presence in the media:**
Strong coverage in dozens of media outlets worldwide, including:

- BBC News - 'Under the skin' blood-testing device developed
- le figaro.fr: Un mini-laboratoire sous la peau
- bild.de: Dieser Chip kontrolliert ihr Blut
- El Mundo - Un diminuto laboratorio portátil bajo la piel
- corriere.it: Sotto pelle laboratorio analisi sangue
- dailymail: The medical lab implanted under the skin that can automatically phone a doctor BEFORE you fall ill
- The Times of India: Now, a device to predict heart attacks
- Hong Kong Herald - Mini 'Blood Labs' Can Predict A Heart Attack
- NZZ: Blutanalyse unter der Haut
- die Welt: Mini-Labor unter der Haut kontrolliert Blutwerte
- Tages Anzeiger: Ein Blutlabor, das unter die Haut geht

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Jacopo Olivo, Sandro Carrara, Giovanni De Micheli, Biofuel Cells and Inductive Powering as Harvesting Techniques for Implantable Sensors, Science of Advanced Materials, 3(2011), 420-425

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Sandro Carrara, Sara Seyedeh Ghoreishizadeh, Jacopo Olivo, Irene Taurino, Camilla Baj-Rossi, Andrea Cavallini, Maaike Op de Beeck, Catherine Dehollain, Wayne Burleson, Francis Gabriel Moussy, Anthony Guiseppi-Elie, Giovanni De Micheli, Fully Integrated Biochip Platforms for Advanced Healthcare, Sensors 12, 11013-11060 (2012)

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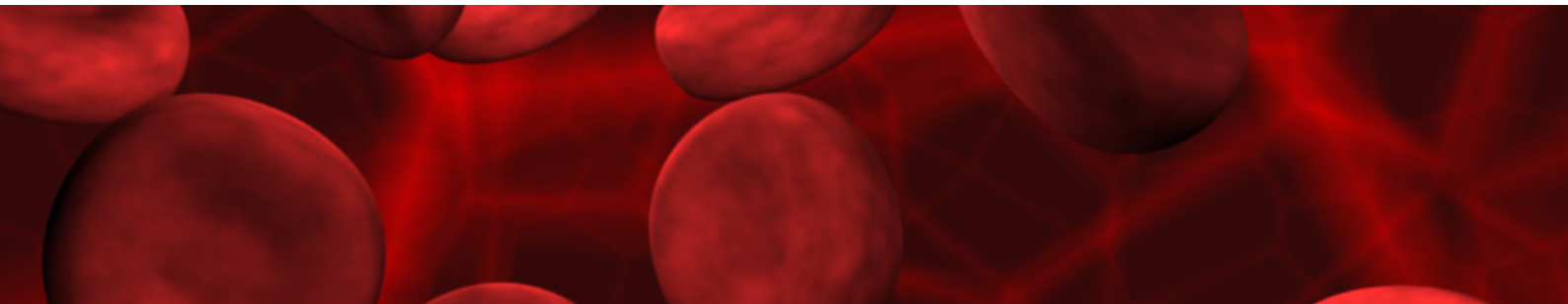
Irene Taurino, Viviane Van Hoof, Giovanni De Micheli, Sandro Carrara,, Superior sensing performance of MWCNT-based electrodes to detect unconjugated bilirubin, Thin Solid Films 548, 546-550 (2013)

Jacopo Olivo, Sandro Carrara, and Giovanni De Micheli,, A study of Multi-Layer Spiral Inductors for Remote Powering of Implantable Sensors, , IEEE Transaction of Biomedical Circuits and Systems 7(2013) 536-547

Jacopo Olivo, Sandro Carrara, and Giovanni De Micheli,, Micro-fabrication of high-thickness spiral inductors for the remote powering of implantable biosensors, , Journal of Micromechanics and Microengineering, 113 (2014) 130-135

Fabrizio Mastrantonio, Francesco Valgimigli, Lucia Grassi, Paolo Cappa, Giovanni De Micheli, Sandro Carrara,, Comparative Performance of Different Nanostructured Electrochemical Sensors on Insulin Detection, , BioNanoScience 2(2013) 1-4

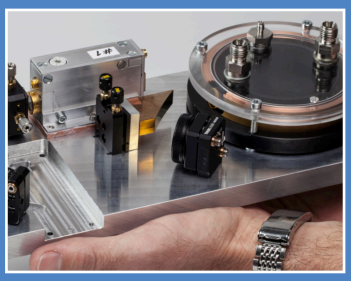
Irene Taurino & Reiss Renate, Michael Fairhead, Michael Richter, Linda Thšny-Meyer, Giovanni De Micheli, Sandro Carrara,, Comparative study of three lactate oxidases from Aerococcus viridans for biosensing applications, Electrochimica Acta, 93 (2013) 72-79

Prof. Jérôme Faist, ETHZ

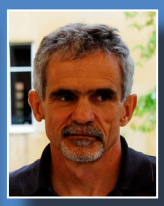
# IrSens

## INTEGRATED SENSING PLATFORM FOR GASES AND LIQUIDS IN THE NEAR AND MID-INFRARED RANGE

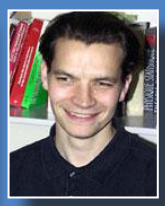


Prof. Edoardo Charbon, EPFL

Dr. Lukas Emmenegger, EMPA



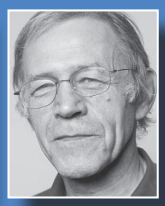
Prof. Hans Peter Herzig, EPFL



Dr. Daniel Hofstetter, UniNE

Dr. Alexandra Homsy, EPFL

Prof. Eli Kapon, EPFL



Prof. Herbert Looser, FHNW

Prof. Markus Sigrist, ETHZ

### What it's about…

***Developing two platforms to measure cocaine concentration in saliva and $CO_2$ isotopes ratio in air to demonstrate the feasibility of compact, low consumption and state of the art detectivity sensors for both liquids and gases using near- and mid-infrared spectroscopy.***

### Context and project goals

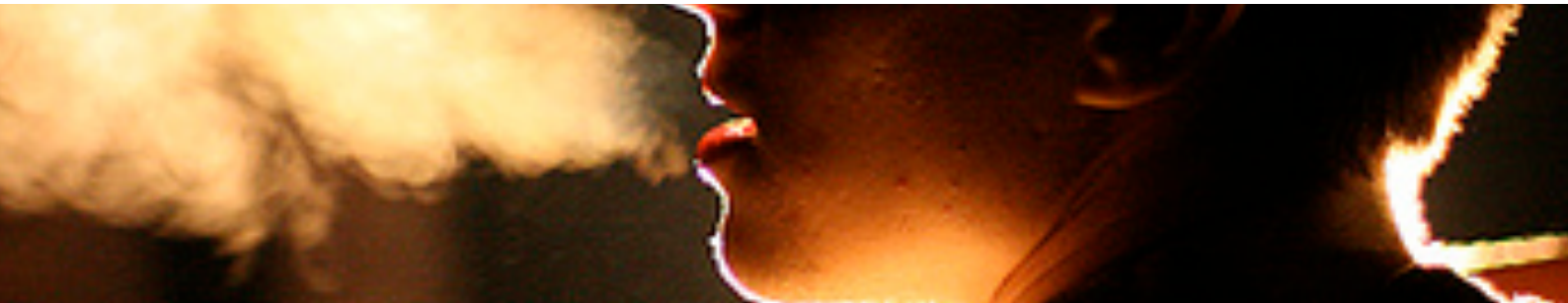
In the context of increasing demand for sensitive, selective, fast and portable detectors for trace components in gases and liquids, e.g due to increasing concerns about atmospheric pollutants, and to needs for improved medical screening capabilities for early detection of diseases and drug abuse, the project goal was to build, low cost and robust platform based on optical spectroscopy in the near- and mid-infrared range.

### How the project differentiates from similar competition in the field

This project is particular as it aims at building two prototype systems allowing to work in near- and mid-infrared, with fluids and gases, but still portable and small with low power demands acceptable for remote monitoring applications. It therefore combines several of the targets of other programs like MIRTHE (NSF, USA), DARPA Center for Optofluidic Integration or NRC ICT Sector (NRC-CNRC, Canada).

### Quick summary of the project status and key results

All the work packages have achieved their goals. For the gas sensor, state of the art measurements have been achieved with the laboratory setup for measurements of the ratio of different $CO_2$ isotopes with a real time fitting dedicated software. A very compact version of this setup was then built with a foot print smaller than an A4 sheet thanks to the development of QCLs and QCD. Very good measurements for $CO_2$ isotopes measurement have as well been obtained with this demonstrator. For the liquids, a deep benchmarking study allowed to find adequate solvent and curable glue to engineer a sensor for cocaine detection. A very inexpensive microfluidic system was successfully developed to extract cocaine from saliva into a solvent and was then soldered on top of a Si/Ge waveguide. This demonstrator allowed direct measurement of cocaine concentration in a saliva sample. An alternative sensor was as well realized with optical fibers and gave a limit of detection of less than 250 ng/mL. Very good results were obtained in the same time on development of SPADs and VCSELs.



## Success stories

- Realization of a portable gas sensor demonstrator with precision of 0.02 % for the measurement of $CO_2$ isotope ratios
- Realization of a liquid sensor with a limit of detection lower than 250 ng/mL of cocaine in solvent
- Development of VCELs with a process suited for industrial production for fiber optical communications
- ATR measurements for early detection of periodontitis disease
- Very good interaction between several groups of the project to assemble both sensor demonstrators

### Presence in the media

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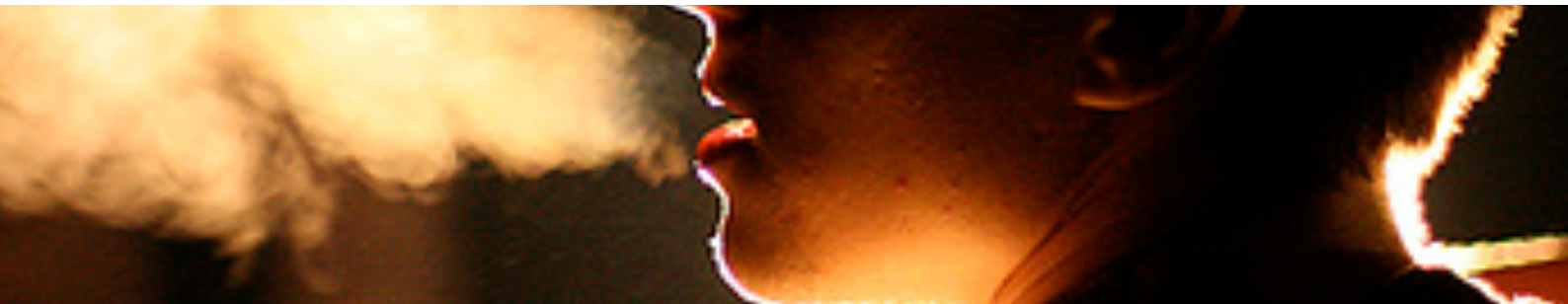
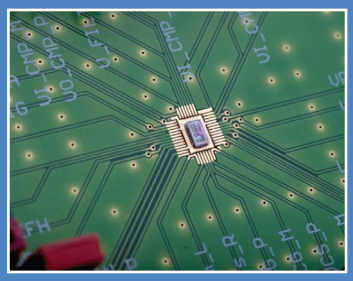


Prof. Carlotta Guiducci, EPFL

# ISyPeM

## INTELLIGENT INTEGRATED SYSTEMS FOR PERSONALIZED MEDICINE



Dr. Thierry Buclin, CHUV

Prof. Giovanni De Micheli, EPFL

Prof. Christian Enz, CSEM

Prof. Carlos-Andrés Pena-Reyes, HEIG-VD

**What it's about…**

***Improving medical practice by enabling personalized medicine via therapeutic drug monitoring, while reducing health care costs.***

**Context and project goals**

The purpose of the research was to advance the state-of-the-art in personalized medicine by creating new enabling technologies for drug monitoring and delivery rooted in the combination of sensing, in situ data processing, and drug release control mechanisms. The project explored new sensor technologies, hardware and software data processing means, and drug release mechanisms based on silicon membranes. This combination of new technologies can significantly better medical care and reduce the related costs.

**How the project differentiates from similar competition in the field**

The project improves the state of the art by providing: (i) new point of care sensing systems (based on transmission SPR) and more robust probe molecules for specific drugs (based on DNA aptamers), (ii) new drug delivery mechanisms via electronically-controlled silicon membranes and (iii) an innovative approach to dose computing based on a formal design methodology for provably correct and safe electronic drug delivery.

**Quick summary of the project status and key results**

Since it's beginning, the ISyPeM project has generated more than 30 publications in peer-reviewed international high impact journals and conferences (and more are in preparation), including results issue of the collaboration of different groups of the consortium. Besides the scientific impact of the work, ISyPeM has focused on software and technological development. HEIG-VD work defined new dose-computing approaches and developed an exhaustive therapeutic drug monitoring user interface. The facilities in CMi and CSEM developed new integrated sensors and nanoporous membranes for drug release.

**Patent**

Method for CMOS-Compatible Chip-to-Chip 3D Integration, Yuksel Temiz, Michael Zervas, Carlott Guiducci, Yusuf Leblebici.

## Success stories

Carlotta Guiducci was invited speaker to two important conferences in 2013: (EMBC 2013) IEEE Engineering In Biology and Medicine Society Conference and (IEDM 2013) IEEE International Electron Devices Meeting.

The highly ergonomic user interface for medical doctors to enable formalized therapeutic drug monitoring is now on line: www.ezeCHiel.ch . This tool is the result of the collaboration among three partners of ISyPeM (CHUV, HEIG-VD, EPFL-LSI).

ISyPeM won the best video award at the Nano-Tera annual meeting 2013.

Five demonstrators were presented to the 2013 Nano-Tera annual meeting who saw as well the participation of STMicroelectronics at the project stand.

**Presence in the media:**
Carlotta Guiducci's interview at RTS: http://www.rts.ch/la-1ere/programmes/cqfd/4719239-rencontre-avec-carlotta-guiducci-22-03-2013.html

### Main publications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F. Montagne, N. Blondiaux, A. Bojko, R. Pugin, Molecular transport through nanoporous silicon nitride membranes produced from self-assembling block copolymers, Nanoscale, 4, 5880 (2012)

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A. Fuchs, C. Csajka, Y. Thoma, T. Buclin, N. Widmer, Benchmarking therapeutic drug monitoring software: A review of available computer tools, Clin Pharmacokinet. 2013 Jan;52(1):9-22

A. Fayet-Mello, T. Buclin, N. Guignard, S. Cruchon, M. Cavassini, C. Grawe, E. Gremlich, K. Aebi Popp, F. Schmid, C.B. Eap, A. Telenti, J. Biollaz, L.A. Decosterd, B. Martinez de Tejada, The Swiss HIV Cohort Study and the Mother & Child HIV Cohort Study. Free and total plasma levels of lopinavir during pregnancy, at delivery and in postpartum: implication for dosage adjustments in pregnant women. , Antivir Ther. 2013;18(2):171-82

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Viswanathan Balasubramanian, Pierre-Francois Ruedi, Yuksel Temiz, Anna Ferretti, Carlotta Guiducci, and Christian C. Enz, A 0.18 Biosensor Front-End Based on Noise, Distortion Cancelation and Chopper Stabilization Techniques, IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, VOL. 7, NO. 5, 2013

Enrico Accastelli, Giulia Cappi, Julien Buckley Barbara De Salvo, Carlotta Guiducci, Comparison between front- and back-gating of Silicon Nanoribbons in real-time sensing experiments, IEEE NANO 2013, in press

Yuksel Temiz, Carlotta Guiducci and Yusuf Leblebici, Post-CMOS Processing and 3-D Integration Based on Dry-Film Lithography, IEEE Transactions on Components, Packaging and Manufacturing Technology, Components, Packaging and Manufacturing Technology, vol. 3, no.9, pp. 1458,1466, 2012

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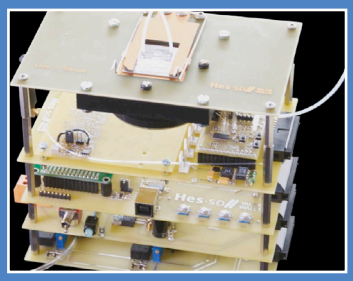
Aravind Heragu, David Ruffieux, Christian Enz, The Design of Ultralow-Power MEMS-Based Radio for WSN and WBAN, Frequency References, Power Management for SoC, and Smart Wireless Interfaces, 2014, pp 265-280


Prof. Philippe Renaud, EPFL

# LiveSense

## INTEGRATED SENSING PLATFORM FOR GASES AND LIQUIDS IN THE NEAR AND MID-INFRARED RANGE



Prof. Martial Geiser, HESSO-VS

Prof. Hubert Girault, EPFL

Dr. Martha Liley, CSEM

Dr. Michael Riediker, IST

Prof. Nico de Rooij, EPFL

Prof. Jan van der Meer, UNIL

Prof. Viola Vogel, ETHZ

**What it's about…**

***Building an early-warning system for environmental monitoring using cell-based sensors***

**Context and project goals**

Environmental monitoring is crucial to preserve the health of humans and animals. The project goal was to develop semi-autonomous sensing nodes that sense water quality and rely results to a remote risk management center. The idea was to rapidly detect any potential threat in the environment, thus the consortium prioritized high selectivity over high specificity.

**How the project differentiates from similar competition in the field**

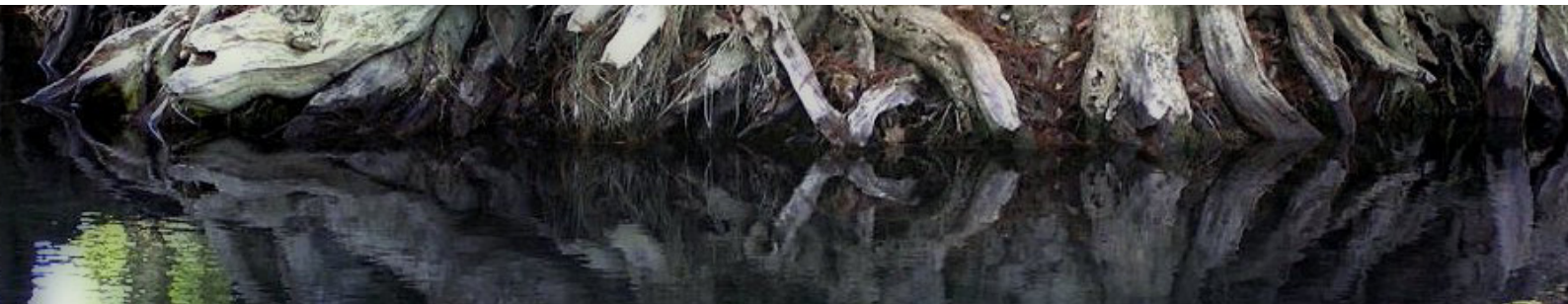
The team built from the bottom up a semi-autonomous platform that supports cell-based sensing and sends results over the cellular network to a remote user. Most, if not all, competitors have so far only demonstrated cell-based sensing in a laboratory setup. Here, the project engineered a system for field application.

**Quick summary of the project status and key results**

The bioreactors with cell models are functional and have been integrated to the environmental sensing system. The module to automatically adjust the osmolality of the water sample before introducing it in the bioreactor is also functional. The secondary sensors: fluorescence, electrochemical, impedance, mechanical and trans-epithelial electrical resistance; are functional and characterized using the cell models. The modular system to be used in actual environmental monitoring has been built according to specifications and validated by characterizing the relation between the fluorescence intensity and the concentration of arsenic in a sample. Basic remote control of this system using a smart phone has also been demonstrated. The project developed as expected. Detection techniques to monitor the signal emitted by the cell-based sensors were all validated in the lab. Conditioning of the water sample has also been achieved. Next three selected detection techniques were integrated into the demonstrator prototype and established the final control routines of all modules featured in the demonstrator. The functionality with distance control by means of SMS was also demonstrated.

**Patent**

LMIS considers filing a patent for a method of drug resistance screening for cancer biopsy.



## Success stories

The collaboration between SAMLAB and CSEM-Neuchatel is continued as well. Seeding the epithelial cells and providing cell-culture medium samples for the metabolism measurements is performed by CSEM.
In the HES-SO//Valais, two institutes were involved, and about 30 persons have contributed to the project. This was the first project that so many collaborators were working together. This ranged from analog electronics, to optimization of bacteria culture by passing through computer programming, mechanical design and fabrication, microfluidic and optics.

ETHZ started collaborations with Edna Cukierman (Fox Chase Cancer Center, Philadelphia, USA) and Martin Schwab, (UZ/ETH D-HEST); the Schwab collaboration resulted in a PNAS 2013 publication.

### Presence in the media

- Newspaper Le Nouvelliste, 4.09.2013 : Traquer les eaux polluées
- Brochure International Innovation, August 2013 : pollution solutions
- Online magazine Artemis, April 2013: The Right Dose for Oncology

### Main publications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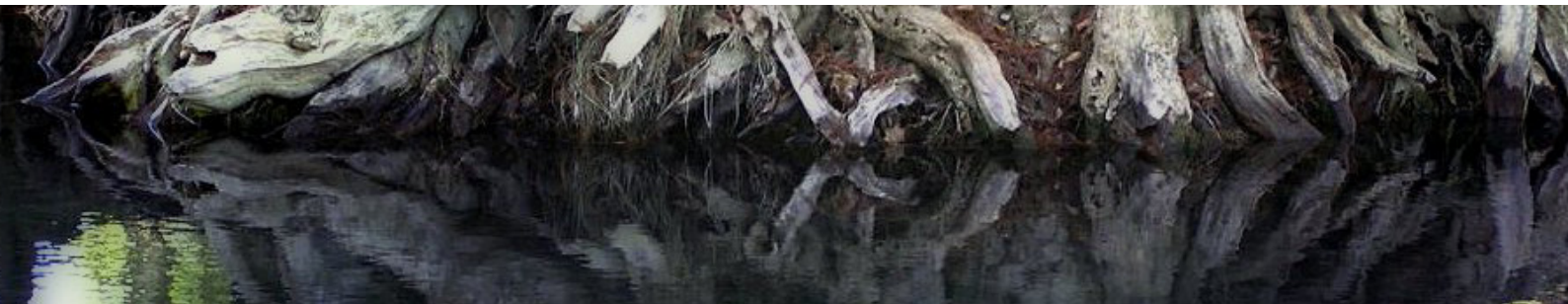
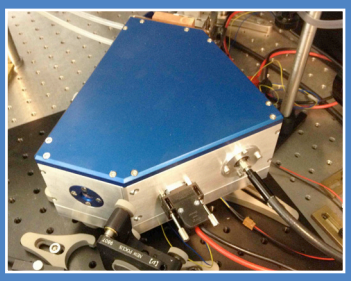


Prof. Ursula Keller, ETHZ

# MIXSEL

## VERTICAL INTEGRATION OF ULTRAFAST SEMICONDUCTOR LASERS FOR WAFER-SCALE MASS PRODUCTION



Prof. Eli Kapon, EPFL

Prof. Thomas Südmeyer, UniNE

Prof. Bernd Witzigmann, Uni Kassel

**What it's about…**

***Developing a new class of semiconductor lasers generating ultrashort pulses (in the pico- and femtosecond regime) to enable new industrial applications.***

**Context and project goals**

The project expands the SESAM modelocking approach to a new class of semiconductor lasers with wafer-scale integration of both the gain and the absorber into a vertical emitting structure. The goal is to scale both power and pulse duration to new regimes that enable for example stable frequency comb generation.

**How the project differentiates from similar competition in the field**

The OP-MIXSEL/VECSEL results obtained are all world leading. The consortium is pushing the average power of this technology. A picosecond MIXSEL generated more than 6 W average power, a femtosecond MIXSEL generated more than 100 mW average power, a femtosecond SESAM modelocked VECSEL generated more than 1 W average output power and extremely low noise level performance was demonstrated both for the SESAM modelocked VECSEL as well as for the MIXSEL. Frequency combs based on DPSSLs show superior performance, but are more complex and not producible in a wafer-scale approach.

**Quick summary of the project status and key results**

The semiconductor disk laser technology was moved into the femtosecond domain. With a SESAM modelocked VECSEL, 1W of output power was achieved with sub-picosecond pulses. The MIXSEL was demonstrated with 570 fs pulses and an output power of 127 mW. A record high average output power of 6.4 W was achieved in 28 ps pulses from a MIXSEL. Both the SESAM modelocked VECSEL and the MIXSEL show excellent noise performance comparable to DPSSL. This makes them highly suitable for further frequency comb stabilization.

Full stabilization of a frequency comb (CEO beat and laser repetition rate) has been demonstrated with a SESAM modelocked diode-pumped Er:Yb:glass laser.

Extensive modeling and a well considered design of an EP-VECSEL structure has lead to the shortest pulses from a SESAM modelocked VECSEL reported so far. 6.3 ps pulses were recorded with a 6.2 mW average output power.

**Patent**

A. Sirbu, A. Mereuta, A. Caliman, Vertical cavity surface emitting devices incorporating wafer-fused reflectors, European patent 2449638, 2013.

## Success stories

The wafer fused gain mirrors, developed at EPFL, were implemented into products of a leading industrial player in the VECSEL technology. This one year collaborative project was supported by the Nano-Tera Program and internal resources of the industrial partner.

Mario Mangold and Alexei Sirbu are invited to give a presentation at SPIE Photonics WEST 2014 about the latest femtosecond MIXSEL results and about wafer fused VECSELs in the 1310 nm region (besides a number of contributed talks).

Two European workshops in the field of the MIXSEL project: European laser workshop and European VCSEL day were organized by the EPFL MIXSEL team in Lausanne in 2011 and 2013.

The research also received strong media interest: it was covered by several news articles including two articles in the Photonik International magazine, an article in the SPIE Newsroom and an article in Compound Semiconductors magazine.

### Main publications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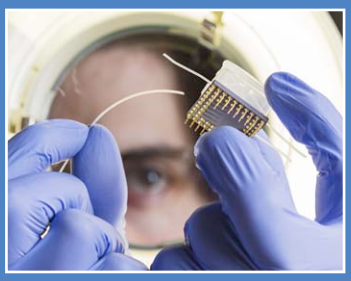
# NanowireSensor

## INTEGRATEABLE SILICON NANOWIRE SENSOR PLATFORM



Prof. Christian Schönenberger, Uni Basel

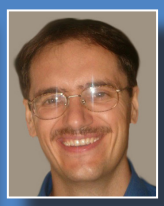
Prof. Beat Ernst, Uni Basel

Prof. Jens Gobrecht, PSI

Prof. Andreas Hierlemann, ETHZ

Prof. Adrian Ionescu, EPFL

Prof. Uwe Pieles, FHNW



Prof. Janos Vörös, ETHZ

### What it's about…

***Exploiting the potential of electronic components, similar to the ones used in state-of-the-art integrated circuits, for biochemical sensing.***

### Context and project goals

Today electronics provides the means for complex computing and drives the communication society. The availability of electronics has been enabled to a large extent by integration technology. In analogy to electronics the same concept of integration is today pursued in analytics and chemical synthesis. These "labs on chips", as they are called, will enable better and faster medical diagnosis. Silicon-based electronic components for biochemical sensing, as they are developed in this project, are crucial elements for such chips.

### How the project differentiates from similar competition in the field

The NANOWIRE SENSOR team is a highly interdisciplinary group of researcher working in physics, system biology, pharmacy, engineering, nanotechnology and surface chemistry. The projects covers all elements from basic science to system integration.

### Quick summary of the project status and key results

In the NANOWIRE SENSOR project arrays of silicon nanowire (NW) field-effect transistors (FETs) were fabricated on a wafer scale. They are realized as double-gated SOI (silicon on insulator) FETs and FinFETs. The NW-FETs are of high quality displaying reproducible threshold voltages, low sub-threshold swing and low noise. Si-NWs were passivated with an ALD-deposited top-oxide made of $Al_2O_3$ or $HfO_2$ for their use in electrolytes. They passivated NWs display low leakage current and high gain in pH measurements with sensitivities close to the Nernst limit. A CMOS readout chip has been realized and electrically validated by reading an array of 16 wires in parallel. The fully integrated system provides a measured resolution of 12 bits and a response time of less than 0.2s in pH test experiments. The consortium has greatly expanded the knowledge on the NW liquid interface by studying the surface potential as a function of ion concentration. A milestone is the successful demonstration of differential measurements with NWs on the same chip that are functionalized differently, as well as the combination of NW-FETs for amplification. The differential measurement greatly increases the long term stability. The sensing experiments were also expanded to lectin proteins.

## Success stories

### Awards

S. Rigante, P. Scarbolo, D. Bouvet, M. Wipf, A. Tarasov, K. Bedner, and A.M. Ionescu, "High-k dielectric FinFETs towards Sensing Integrated Circuits", oral presentation at International Conference on ULTIMATE INTEGRATION ON SILICON, ULIS 2013, Warwick, United Kingdom, awarded as Best Paper (talk).

The consortium continued on the successful demonstration of differential measurements with an array of nanowire (NW) sensors with different functionalization. Building on potassium sensing demonstrated earlier in the project, the team has now realized a sodium ion sensor using the same platform.

The NANOWIRE SENSOR team has early on stressed on the importance of the low frequency noise determining the resolution limit of the sensor. Recently, the team could prove that the 1/f noise in silicon NW ion-sensitive FETs with ALD top-oxide layers originates from trap state fluctuations within this layer and is not caused by dielectric polarization noise. Most recently, it could be shown that the quaility of this oxide layer can further be improved by using a multilayer stack yielding devices with less noise and higher resolution. In this area, but also with the differential and integrated sensing mentioned before, the NANOWIRE SENSOR project has defined the state-of-the art worldwide.

During the whole period the project was monitored by the company Sensirion whose success in their sensing business in the area of mass flow and humidity builds on the capability of integration using CMOS components. Although Sensirion's market is not in ion-sensing, the company could profit from the insight gained within this project, and vice versa, all academic partners and the project gained immensely from the industrial input. Sensirion views this project a scientific success. However, the project has not yet matured to a product, but it has the potential to do so in the near future if research could be continued. The highest potential is in the simultaneous measurements of different ions for chemical and biochemical applications.

### Main publications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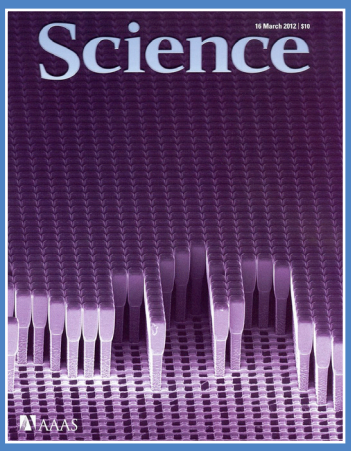
Dr. Alex Dommann, CSEM/EMPA

# Nexray

## NETWORK OF INTEGRATED MINIATURIZED X-RAY SYSTEMS OPERATING IN COMPLEX ENVIRONMENTS




Dr. Pierangelo Gröning, EMPA

Prof. Hans von Känel, ETHZ

**What it's about…**

***Enabling completely new modes of X-ray imaging, which will e.g. be extremely useful for applications ranging from emergency medicine to landmine detection.***

**Context and project goals**

This project targets the development of novel pocket X-ray sources and X-ray direct detectors that will be combined in a distributed network to facilitate X-ray imaging in areas where it was not used up to now.

Miniaturized X-ray sources based on carbon nanotube (CNT) cold electron emitters combined with advanced microsystems packaging technology, together with X-ray direct detectors based on crystalline Germanium ab-sorption layers integrated in CMOS sensor chips open the way to radical new approaches to X-ray imaging, in-cluding X-ray time-of-flight (xTOF) measurements based on Compton or static tomography without any moving parts.

**How the project differentiates from similar competition in the field**

CNT based electron emission, vacuum tight MEMS packaging, epitaxy of hetero-layers and pulse counting circuits per se are not completely new. The novelty of this approach is the combination of these technologies to enable radically new modes of operation in X-ray imaging. In this sense this project is unrivalled in the scientific landscape.

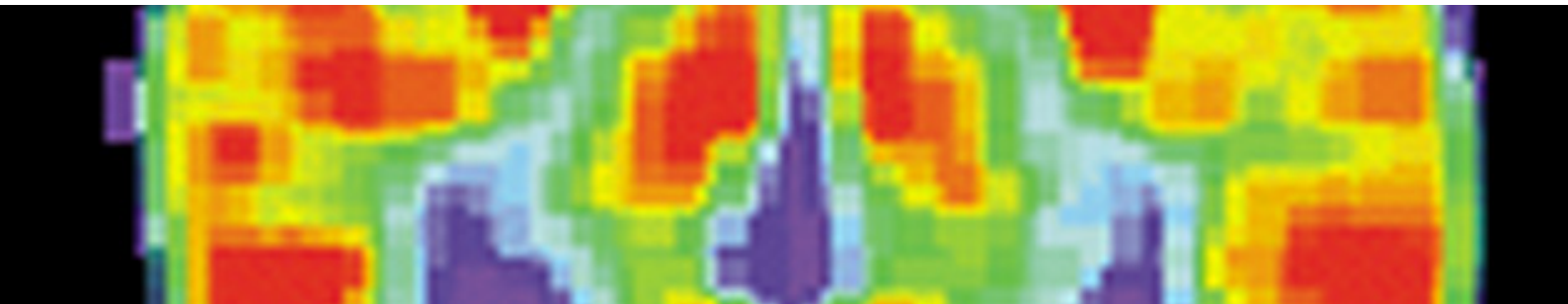
**Quick summary of the project status and key results**

The consortium produced pocket X-ray sources with a size of about 0.1 $cm^3$, carbon nanotube electron emitters and a vacuum level < $10^{-3}$ mbar. These sources produced X-rays of about 3 keV. On the detector side the team produced technology demonstrators with monolithically integrated Ge absorption layers on a CMOS chip, which could detect X-rays of 8 keV energy. In parallel a fully functional CMOS circuit was developed.

The main scientific achievements are a breakthrough in epitaxy to grow thick layers of Ge on Si, which made it on the cover page of the Science magazine in March 2012 and generated ample scientific press coverage. Other scientific successes include the development of high-vacuum tight MEMS packaging technologies and a novel carbon nanotube production method.

**Patent**

Hans von Känel, Leo Miglio: US2013037857 (A1)



## Success stories

The most striking success story is certainly the structured epitaxial growth of thick Germanium layers on Silicon. This was a major breakthrough which was used as a cover story of the Science magazine on March 16th, 2012 and which was also mentioned in many other media.

The team also managed to prove that these structured Ge layers can be grown on preprocessed CMOS wafers with a high temperature metallization and that such devices are capable of detecting X-rays. This is a proof of concept that the planned devices work.

In parallel a fully working CMOS circuit was developed and produced which fulfills all specs and shows a very good uniformity and noise-level.

For the X-ray sources it was possible to show that X-rays could be produced in a vacuum chamber with more than 3 kV acceleration voltage and less than 5 mm spacing between cathode and anode. This is a great step towards an integrated, miniaturized source. The proof was made using a dental X-ray film.

A clear highlight was also the development of a novel carbon nanotube cathode fabrication technology based on the soldering of macroscopic multiwall nanotube films, which outperforms the existing CNT cathode arrays in terms of the minimally required extraction field. This new development gives the consortium much more flexibility in choosing an optimized CNT cathode depending on the target application.

Another success story is the development of high-vacuum tight MEMS packaging methods. A package bonded with a vacuum level of 2x10-5 mbar was able to hold successfully hold a level ≤ 10-3 mbar, which is already close to what is required for the final device.

### Main publications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T. Kreiliger, C.V. Falub, A.G. Taboada, F. Isa, S. Cecchi, R. Kaufmann, P. Niedermann, A. Pezous, S. Mouaziz, A. Dommann, G. Isella, H. von Känel, Individual heterojunctions of 3D germanium ctystals on silicon CMOS for monolithically integrated X-ray detector, Phys. Status Solidi, in press

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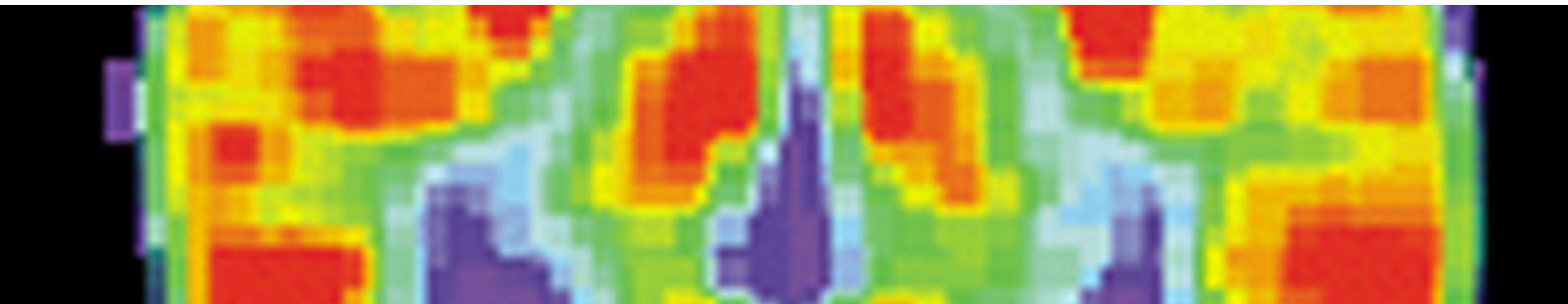
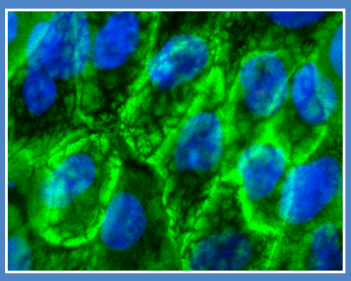


Prof. Martin Gijs, EPFL

# NutriChip

## A TECHNOLOGICAL PLATFORM FOR NUTRITION ANALYSIS TO PROMOTE HEALTHY FOOD



Dr. Sandro Carrara, EPFL

Prof. Richard F. Hurrell, ETHZ

Prof. Jeremy Ramsden, ColBas

Dr. Guy Vergères, ALP

**What it's about…**

***Developing a miniaturized model of the human gut that aims at screening food products for their ability to modulate our metabolic and immune system.***

**Context and project goals**

The NutriChip project's goal was to develop an integrated platform to investigate the potential of immunomodulation properties of dairy products. The NutriChip would provide steady-state culture conditions that mimic the in vivo fluid flow and shear stress in controllable manner, thus bringing the gut in vitro model closer to the physiological micro-environment.

**How the project differentiates from similar competition in the field**

The consortium is not aware of a translational nutritional academic project that covers so widely the research fields of food and nutritional sciences, additionally complementing these fields with work on imaging hardware, software and chip technologies.

**Quick summary of the project status and key results**

An *in vitro* Gastro Intestinal Tract (GIT) model was established, consisting of a co-culture of an intestinal cell monolayer, which acts as a barrier mediating the active transcellular transport of nutrients, and macrophages, which act as sensors for the presence of immunomodulatory molecules secreted by the epithelial cells. Using this model, it was possible to differentiate between the immunomodulatory properties of meal rich in saturated fat and milk. The same cell lines used in the Transwell model have been successfully cultured on chip. A Complementary Metal Oxide Semiconductor (CMOS) technology-based camera was custom-built and a full CMOS image sensor was designed. The realized image sensor was successfully tested and a second prototype that is now larger in terms of pixels was designed. The team has also implemented on a Field-Programmable Gate Array (FPGA) the algorithm developed for quantitative estimation of biomarkers related to postprandial inflammation in order to move toward the possibility of a real-time acquisition of such kind of data. The researchers performed a postprandial inflammation human study after ingestion of a high fat meal by obese and lean individuals.

**Patent**

Gözen Küklü, Demirci Tugba, Giovanni De Micheli, Sandro Carrara, A novel High Dynamic Range CMOS Image Sensors with Event/ Change Detection and Data Compression, Provisional US Patent Office Application, year 2013, Filing # 61/816,197.

## Success stories

In the context of the research program 2014-2017, the project partner Agroscope has created, as of 01.01.2014 a new domain of competence "Functional Nutritional Biology" that will be headed by Guy Vergères and that aims at identifying lactic acid bacteria that ferment milk to products with enhanced nutritional properties. This would not have been possible without the pioneering work conducted in the NutriChip project.

Agroscope has also signed a research agreement with CHUV, which also not have been possible without the results obtained on human nutrition and dairy products in the NutriCip project.

The article by Ramadan et al., published in Lab-on-chip, was recently selected by researchers from the Boston area (Harvard, MIT) in a review highlighting important developments in the microfluidic sciences. It was mentioned as 'Research Highlight' in Lab on a Chip 13, issue 15 of August 7th 2013.

**Presence in the media:**
Guy Vergères was cited in an article in Le Temps "Je m'alimente selon mon génome"

### Main publications


G. Vergères, B. Bogicevic, C. Buri, S. Carrara, M. Chollet, L. Corbino-Giunta, L. Egger, D. Gille, K. Kopf-Bolanz, K. Laederach, R. Portmann, Q. Ramadan, J. Ramsden, F. Schwander, P. Silacci, B. Walther, M. Gijs, The NutriChip project-Translating technology into nutritional knowledge, British Journal of Nutrition, 108, 762–768, (2012).

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G. Vergères, Nutrigenomics - linking food to human metabolism, Trends in Food Science & Technology, Volume 31, Issue 1, May 2013, Pages 6–12


# OpenSense

## OPEN SENSOR NETWORKS FOR AIR QUALITY MONITORING

Prof. Karl Aberer, EPFL

Prof. Boi Faltings, EPFL

Prof. Alcherio Martinoli, EPFL

Prof. Lothar Thiele, ETHZ

Prof. Martin Vetterli, EPFL

**What it's about…**

***Providing accurate, real-time information about air quality to users interested in health and environmental issues by using low-cost, mobile sensors.***

**Context and project goals**

Mobile communications and inexpensive embedded sensors open new opportunities in terms of environmental monitoring, such as air quality. However, the impact of doing such measurements on a massive scale, with uncontrolled mobility and end user involvement is not well understood nowadays. This poses novel challenges in terms of system architecture, distributed algorithms and data analysis that are addressed in this project.

**How the project differentiates from similar competition in the field**

- OpenSense is quite unique in terms of producing dense measurements in the domain of air pollution monitoring using mobile measurement stations and aiming at long-term measurements.
- OpenSense deals with a difficult measurement problem (as compared to other participatory sensing projects that use readily available data, e.g. from smartphones such as sound, accelerometer and GPS data).
- OpenSense is unique in adopting an end-to-end systems perspective assembling IT expertise concerning all system layers, whereas comparable projects usually focus on specific sub-problems.

**Quick summary of the project status and key results**

The full sensor deployment was completed for the city of Zürich, with ten sensor boxes on top of trams monitoring a wide range of pollutants on an area of 100 km2. The deployment in Lausanne, has also generated useful data with only a few nodes and different prototype versions. The finalized deployment (12 nodes in total, including ten on buses and one on an electrical car) is currently been deployed in Lausanne. Nodes in both deployments share similarities in sensing modalities, but show complementary design choices in terms of computation, localization, and flow pre-processing.

Techniques have been developed for ensuring quality and trust in the huge amount of data generated by the mobile sensors. Different modeling methods were explored and improved to be able to produce high quality and fine-grained pollution maps, such as region-based Gaussian models or land use regression models.

Sensor placement and scheduling was also optimized for reducing duplicates and correlated measurements, thus improving resource usage of the sensing nodes. But the vicinity of sensors can also be leveraged for calibration and, based on the new concept of Rendezvous Graph, a calibration and faulty sensor detection scheme was developed.

## Success stories

- The OpenSense Zurich deployment was presented at the IoT Zurich Walkshop. A City WalkShop is a short engaging activity to involve people in the physical world of a city, to observe and to document where the digital world is sensing our presence and our environment while we are part of it (http://zurich.walkshop.org).
- The OpenSense video presentation won the second best prize at the Nano-Tera annual meeting 2013 in Bern.
- Samsung Research (Palo Alto) granted to the group of K. Aberer a 1 year award to continue research on activity recognition originated in the OpenSense project.
- Citroën Switzerland and the Transportation Center at EPFL donated a C-zero electrical vehicle to the group of A. Martinoli to extend the mobility of the sensor network in Lausanne and explore opportunities of private vehicle involvement in the follow-up project OpenSense II.

**Presence in the media:**
The mobile application used for the user study in Zürich generated some interest from the press:
- 24Heures (12.03.2013)
- Le Temps (12.03.2013)
- Netzwoche (05.2013)

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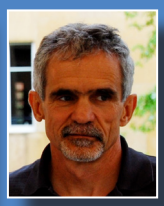
# PATLiSci

PROBE ARRAY TECHNOLOGY FOR LIFE SCIENCE APPLICATIONS

Dr. Harry Heinzelmann, CSEM

Prof. Jürgen Brugger, EPFL

Prof. Nico de Rooij, EPFL



Prof. Hans Peter Herzig, EPFL

Dr. Agnese Mariotti, CePO

Prof. Ernst Meyer, Uni Basel

Prof. Pedro Romero, UNIL

Prof. Horst Vogel, EPFL

**What it's about…**

***Developing techniques based on nanomechanical cantilevers for the non-invasive detection and further scientific investigation of cancer.***

**Context and project goals**

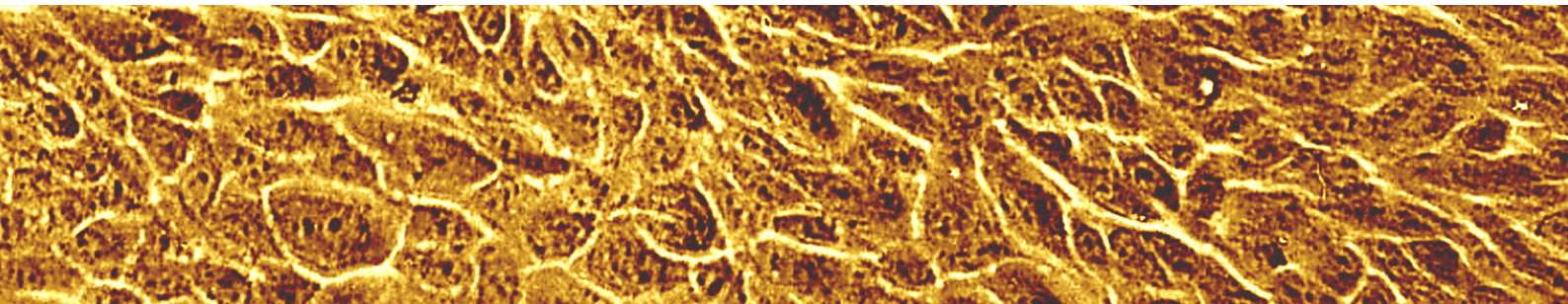
Methods that allow the routine, early, non-invasive detection of cancer will allow early treatment with better survival rates. The development of laboratory tools for the screening of cancer drugs on a cell level, allowing monitoring the cells' adhesion and biomechanical responses, represent promising paths in the search of cancer therapies. The projects objectives include the optimization of nanomechanical sensing for early cancer detection, with a case study for head and neck cancer patients. Further, parallel force spectroscopy is being developed that allow the statistically relevant examination of the nanomechanical responses of numerous cells simultaneously.

**How the project differentiates from similar competition in the field**

The nanomechanical sensing technology allows for direct detection of melanoma without amplification or labeling of RNA samples from cells and for non-invasive detection of head and neck cancer using breath samples, and a rapid evaluation of results. As for force spectroscopy, current technology is limited to single cell adhesion and elasticity measurements, not suitable for screening applications.

**Quick summary of the project status and key results**

Nanomechanical cantilever array sensors have been applied to detect mutant BRAFV600E which allows to apply personalized therapies for the cure of melanoma. Detection was successful in PCR products as well as in total RNA extracted from mutant cancer cell lines. The low concentration of total RNA required (20 ng/µL) indicates that this approach is applicable to clinical material. Procedures for capturing melanoma cells using cantilevers have been established. Using novel membrane-type surface stress sensors (MSS) it was possible to detect head & neck cancer and follow the treatment efficacy in an non-invasive way by investigation of exhaled breath from head & neck cancer patients. Several generations of micromechanical structures were designed, fabricated and tested for parallel force spectroscopy, characterizing elastic properties of cancerous cells by means of acquisition of numerous force curves in parallel, whereby different detection concepts have been evaluated.



## Success stories

The publication by Huber et al. in Nature Nanotechnology 8(2013): 125-129 that describes some of the findings achieved in PATLiSci raised quite substantial public interest. An assay based on microcantilever arrays that can detect a mutation nanomechanically without amplification in total RNA samples isolated from melanoma cells is helpful for identifying the eligibility for treatment of a patient using a specific personalized therapy. The article was highlighted in Nature Nanotechnology and referred to in news portals and the press.

**Presence in the media:**

- 05.02.2013: Press release University of Basel "Nanosensoren unterstützen Therapie von Hautkrebs"
- 05.02.2013: Press release University of Basel "Nanosensors support skin cancer therapy"
- 05.02.2013: myScience.ch "Nanosensoren unterstützen Therapie von Hautkrebs"
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- 26.02.2013: Cancer Commons "Researchers Develop Microscopic Cantilever to Detect BRAF Mutations"

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J. Henriksson, M. Gullo and J. Brugger, Integrated long-range thermal bimorph actuators for parallelizable bio-AFM applications, IEEE Sensors Journal 13, 2849 - 2856 (2013)

F. Loizeau, H.P. Lang, T. Akiyama, S. Gautsch, P. Vettiger, A. Tonin, G. Yoshikawa, Ch. Gerber, N. de Rooij, Piezoresistive Membrane-Type Surface Stress Sensor Arranged In Arrays For Cancer Diagnosis Through Breath Analysis, Proc. 26th IEEE International Conference On Micro Electro Mechanical Systems MEMS 2013, p. 621-624 (2013)

F Huber, HP Lang, N Backmann, D Rimoldi, C Gerber, Direct detection of a BRAF mutation in total RNA from melanoma cells using cantilever arrays, Nature nanotechnology 8 (2), 125-129 (2013)

J Zhang, HP Lang, F Battiston, N Backmann, F Huber, C Gerber, Development of Robust and Standardized Cantilever Sensors Based on Biotin/Neutravidin Coupling for Antibody Detection, Sensors 13 (4), 5273-5285 (2013)

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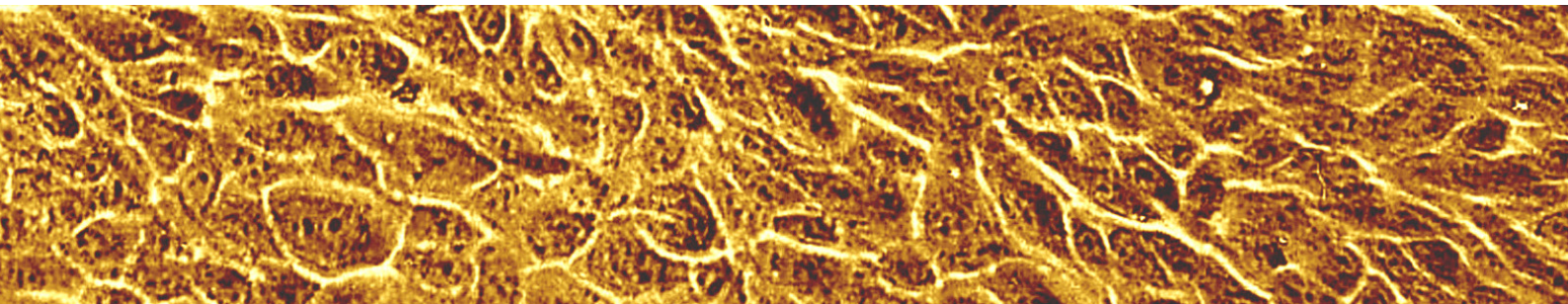
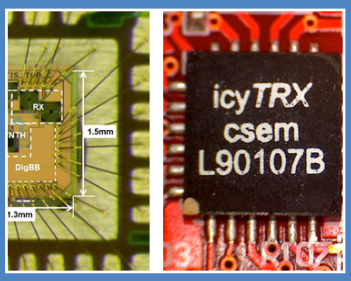


# PlaCiTUS

## PLATFORM CIRCUIT TECHNOLOGY UNDERLYING HETEROGENEOUS NANO AND TERA SYSTEMS




Prof. Qiuting Huang, ETHZ

Dr. Catherine Dehollain, EPFL

Prof. Christian Enz, CSEM/EPFL

### What it's about…

***Mastering complex system design in the nano transistor era, and combining heterogeneous circuit technologies into a versatile platform to support health related sensor networks.***

### Context and project goals

Advances in information and communication technologies, combined with those in wireless communications and sensor networks, have given rise to the idea of Internet of Things. Complex systems, accentuated by the availability of large numbers of nano-scale transistors, pose challenges for their design at both transistor, circuit and system level. Mastering complex system design in the nano device era and applying it to a circuit technology platform to support health related sensor networks and IoT, form the dual objectives of PlaCiTUS.

### How the project differentiates from similar competition in the field

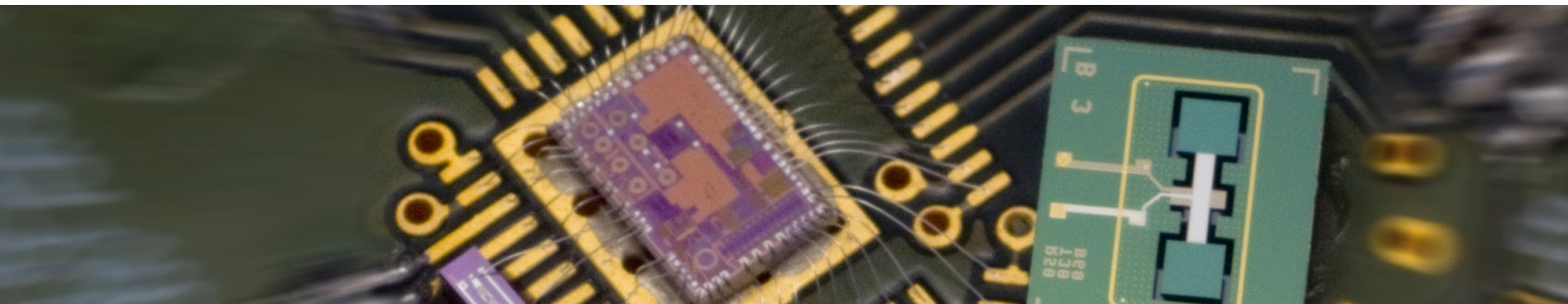
There are quite a number of international centers of excellence in either interface electronics for health-related sensors and implants, wireless communications, and surrounding digital integrated circuits and systems, which is testament to the importance of the subject area. PlaCiTUS combines the Swiss expertise in 3 leading institutions, and aims to distinguish itself in the system optimization by virtue of having sensor interface, WPAN, WWAN and ultra-low power microcontroller in a single consortium. State-of-the-art was achieved so far in data acquisition IC, BTLE IC and LTE transceiver IC in each of the individual areas vis-à-vis leading international competitors, and the team aims to take advantage of these in a combined system.

### Quick summary of the project status and key results

The Placitus project has created excellent results both at the level of integrated circuit design for health applications as well as for system integration and fully operational demonstrators for biomedical application. Main achievements are:

- A multi-channel (8), chopper stabilized EEG/ECG signal acquisition front-end IC with cancellation of mains frequency interference and differential offset due to electrode-skin contact
- A remotely powered, implantable ICs with accurate temperature sensor and low power data transmission capability
- An ultra-low power, 1.95mm2, 2.4 GHz multi-standard short distance transceiver in 90nm standard CMOS technology
- Circuit techniques to realize fractional-integer frequency dividers and to improve the limiting reference linearity of high performance ADCs
- A design methodology to implement quasi continuous active filters spanning a very wide frequency range

Beside several demonstrators of subsystems, a palm-sized EEG/ECG data acquisition system, complete with overall control hardware and software, wireless connectivity (both Bluetooth and 2G/3G cellular), user interface and display on Android based smartphones and tablets, has been realized. Demonstration took place at the Nano-Tera annual meeting in Zurich, at ETH Industry Day, to clinical researchers at the Zurich University Hospital, and was taken on a tour in China as part of a Swiss delegation on Sino-Swiss scientific collaboration.



## Success stories

Prof. Q. Huang has been invited to give a talk at the Stepping Stone Symposium entitled ”A wireless ECG/EEG module with fully integrated multi-channel sensor interface” at the Medical Technology Stepping Stone Symposium - September 27-28, 2012 at ETH Zurich. Around 100 people have attended the symposium.

### Main publications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A. Heragu, D. Ruffieux, J. Chabloz, and C. Enz, A MEMS-based 2.4 GHz Sub-sampling RF Front-end for Advanced Healthcare Applications, Proc. of the IEEE Int. Symp. on RF Integration Technology (RFIT), Nov. 2011 (Invited Paper).

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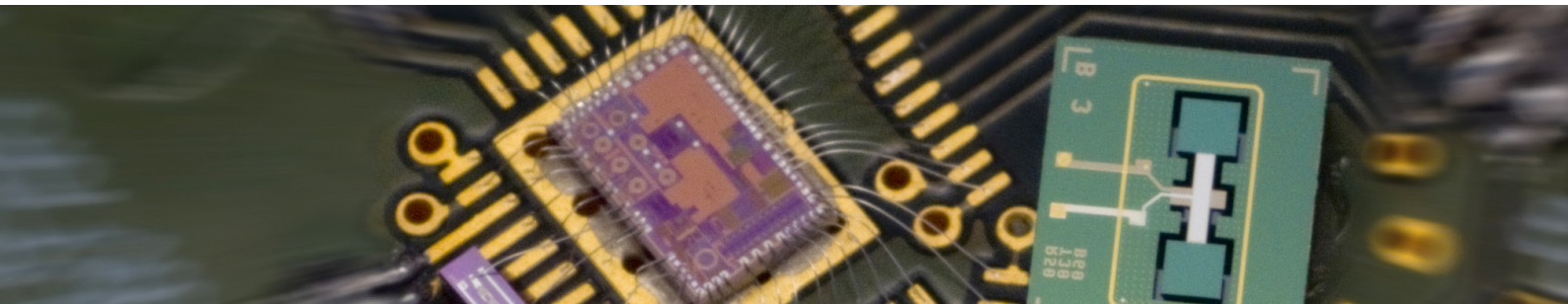

Prof. Nicolas Gisin, Uni Genève

# QCrypt

## SECURE HIGH-SPEED COMMUNICATION BASED ON QUANTUM KEY DISTRIBUTION

Prof. Andreas P. Burg, EPFL

Prof. Norbert Felber, ETHZ

Prof. Etienne Messerli, HES-SO

Dr. Grégoire Ribordy, IDQ

### What it's about…

***Developing a system for sending cryptographic keys whose security is guaranteed by quantum physics and using this key to encrypt data with the highest rate ever of 100 Gb/s.***

### Context and project goals

Today's information society has an ever-growing need for secure data transmission. QCrypt offers at the same time an elegant solution for quantum-secure cryptographic key exchange and data encryption at a world record rate of 100 Gb/s.

### How the project differentiates from similar competition in the field

The QCrypt is, to the team's knowledge, the only project developing both advanced Quantum Key Distribution (QKD) and high-speed encryption systems designed for working together. Moreover, either system is at the cutting edge in its own right: The QKD prototype offers record secure bit rates with real-time hardware based key distillation. In contrast to commercial encryption systems supporting a single link running up to 10 Gbit/s, the encryptors combine ten independent 10G user streams (in plain text) into a single 100 Gbit/s secured stream (encrypted text).

### Quick summary of the project status and key results

In QKD the team has a complete, working prototype with unprecedented real time hardware key distillation, finite key security analyses and fully automated operation over a single fibre using wavelength division multiplexing. On the encryption side, error-free data encryption at 40 Gbit/s with 100% throughput was demonstrated.

### Patents

Patent for the synchronisation of the two QKD devices in preparation.

## Success stories

The complete system including QKD and encryptors was presented at the Nano-Tera.ch annual meeting in Kursaal Berne (see picture). It worked during the two days, under rather difficult conditions with respect to a standard telecom environment, without any interruption.

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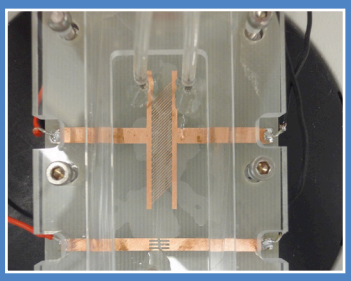
C. Keller, F. Gürkaynak, H. Kaeslin and N. Felber, True Random Number Generation and Unique Identifier Extraction using Dynamic Memoy-Based Physically Unclonable Functions (to be published), Proc. ISCAS International Symposium on Circuits and Systems, Melbourne, Aus (2014)


Prof. Jürgen Brugger, EPFL

# SelfSys

## FLUIDIC-MEDIATED SELF-ASSEMBLY FOR HYBRID FUNCTIONAL MICRO/NANOSYSTEMS



Dr. Helmut Knapp, CSEM Alpnach

Prof. Alcherio Martinoli, EPFL

Prof. Bradley Nelson, ETHZ

M.sc. Laurent Sciboz, RFID Center Sierre

Prof. Nicholas Spencer, ETHZ

### What it's about…

***Developing a completely new manufacturing method based on liquid-mediated self-assembly of smart MEMS parts that are liquid filled and that can release this liquid upon a trigger signal in a self-powered fashion.***

### Context and project goals

The goal of the project is to develop a novel manufacturing method capable of assembling a large number of pre-fabricated smart MEMS devices into more complex systems by using liquid media. An additional goal is to trap liquid inside the assembled MEMS that can be released upon an external trigger signal. These devices may find applications in environmental engineering, drug release, miniaturized chemical systems, etc.

### How the project differentiates from similar competition in the field

The consortium has not seen any other work published that aims for the self-organized assembly of smart MEMS parts that are filled with liquid. Despite the fact that such devices may be fabricated by more conventional assembly techniques, defining a scenario applicable for a large number of very small parts, the use of natural self-assembly forces seems still the only viable solution at this point.

### Quick summary of the project status and key results

The various project parts have been brought to a conclusion: a) MEMS processing using colored SU-8, b) surface functionalization, c) improved control of self-assembly achieved by surface functionalization (hydrophobic, hydrophilic contrast), d) the assembly chamber using piezo-actuators has been improved and modeled in detail allowing for switching between assembly and dis-assembly modes, e) High-speed real-time tracking and control of the MEMS motion has been demonstrated, f) assembly yield statistics established, g) colored ink has been trapped in MEMS and released upon chemical trigger.

## Success stories

SelfSys results have attracted the interest of industry (Debiopharm) which led to a new project proposal (CAPSULE) for controlled drug release that has been retained by the SNSF evaluation for the next Nano-Tera.ch phase.

### Main publications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Prof. Peter Ryser, EPFL

# SImOS

## SMART IMPLANTS FOR ORTHOPAEDICS SURGERY

Prof. Kamiar Aminian, EPFL

Dr. Catherine Dehollain, EPFL

Prof. Pierre-André Farine, EPFL

Prof. Brigitte Jolles-Haeberli, CHUV

M.Sc. Vincent Leclercq, Symbios

Prof. Philippe Renaud, EPFL

### What it's about…

***Designing an innovative knee prosthesis, performing the measurement of biomechanical parameters during and after the implantation, to improve the precision of the surgery and the quality of life of the patient.***

### Context and project goals

The goal of the SImOS project is to design a system to measure biomechanical parameters of a knee prosthesis, in clinical field or during daily activity. This system will be constituted of partly implanted and partly external tools and could help the medical doctors during the surgery and the rehabilitation and increase the quality of life of the patients.

### How the project differentiates from similar competition in the field

The main novelty brought in SImOS project is the direct clinical use of the metrics which are computable based on internal measurements of the Instrumented prosthesis. For instance the estimation of unbalance medial-lateral ligaments based on force measurements on the polyethylene insert, estimation of loosening of the prosthesis, and measurement of kinematics without soft tissue artifact to study the variation in range of motions in sagittal and non-sagittal planes. Second point which differentiates this work from previous studies is the internal (in vivo) measurement of other biomechanical quantities than forces acting on the prosthesis. These quantities include joint angles and translational motions which are not sufficiently accurate in external measurements, and prosthesis-bone micro motion which provides an insight about the loosening of the prosthesis. As the third original feature of SImOS, it is the first time that in vivo (i.e. implanted) and ex vivo (i.e. skin attached) sensors are fused to obtain highly accurate estimations of kinematic and kinetic parameters. Moreover, the choice to instrument only the polyethylene part of the prosthesis instead of a complete custom design of the prosthesis gives a flexibility and compatibility to the SImOS design to be used for all commercially available knee prostheses.

### Quick summary of the project status and key results

- Design of micro-fabrication process and materials for force sensors array fabrication
- Fabrication of a sensor electronics ASIC and a communication and power supply ASIC
- Design and fabrication of the miniaturized system
- Instrumented prosthesis tested with the mechanical knee simulator

## Success stories

Apart from what was told by the TV broadcast organized by Nano-Tera, during the project there was great interest from EPFL students on the topics of the SImOS project. Two journal papers were published with Master students as co-authors. In particular three semester student projects related to SImOS were carried out in 2013 and a new journal paper was submitted.

## Add-on project

An add-on project was carried out, which consisted in building a fully-automated mechanical knee simulator to test the instrumented prosthesis designed in the SImOS project and validate it to be used in a human subject. The goals were multifold, first to build or complete an existing load unit system to be capable to simulate the knee movements and the forces acting on the prosthesis; Second, to control this simulator under different conditions of gait or squat movements while keeping the natural distribution of knee contact forces. By integrating SImOS instrumented prosthesis in the knee simulator, validation is done by actuating it with real data captured from Radiostereometry on 19 subjects, and also existing smart prosthesis data.

Very few mechanical knee simulators exist, the main feature of this simulator is the usage of extra actuators and sensors to simulate and measure the muscles forces acting on the knee. The main difference of this approach with existing ones is to provide the real kinematics and kinetics of a natural knee obtained through real data from biplane fluoroscopy and existing instrumented knee prosthesis. Using a MIMO approach to control the simulator, the smart instrumented prosthesis designed in SImOS is evaluated before implantation. Other kinematic aspects such as patella movement can also be studied during the activity.

The mechanical links for simulating the thigh muscles were completed. A number of stereophotogerammetry markers were placed on the simulator while four cameras were optimally located to measure the 3D kinematics of the knee simulator segments. The real data of bone movements obtained in previous X-ray fluoroscopic measurements over 19 subjects walking on the treadmill were fed to the knee simulator as well as a number of kinematic data from over ground walking. The simulated knee motions were used to validate the implantable AMR sensor-based angle estimation towards the stereophotogrammetry reference. Also two inertial measurement units were fixed on the knee simulator and used to estimate the knee angles. A method to fuse the implanted sensors and the wearable inertial sensors were tested in the knee simulator. The simulator was used to calibrate and validate the new force sensors designed in SImOS in static and dynamic conditions. Also the realistic patterns of knee contact forces were generated to test the measurements of the implantable force sensors. The knee simulator was also used to study the relation between the force and kinematics in the prosthetic knees.

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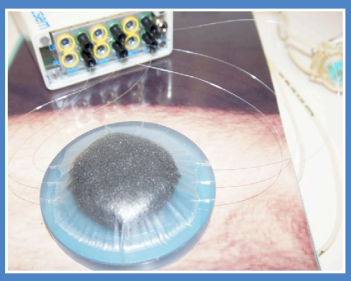
Prof. Gerhard Tröster, ETHZ

# TecInTex

## TECHNOLOGY INTEGRATION INTO TEXTILES: EMPOWERING HEALTH



Dr. Manfred Heuberger, EMPA

M.Sc. Jean Luprano, CSEM

Dr. Guy Voirin, CSEM

Dr. René Rossi, EMPA

Prof. Martin Wolf, USZ

**What it's about…**

***Designing and testing textile based sensors for pressure ulcer prevention and peripheral vascular disease prediction.***

**Context and project goals**

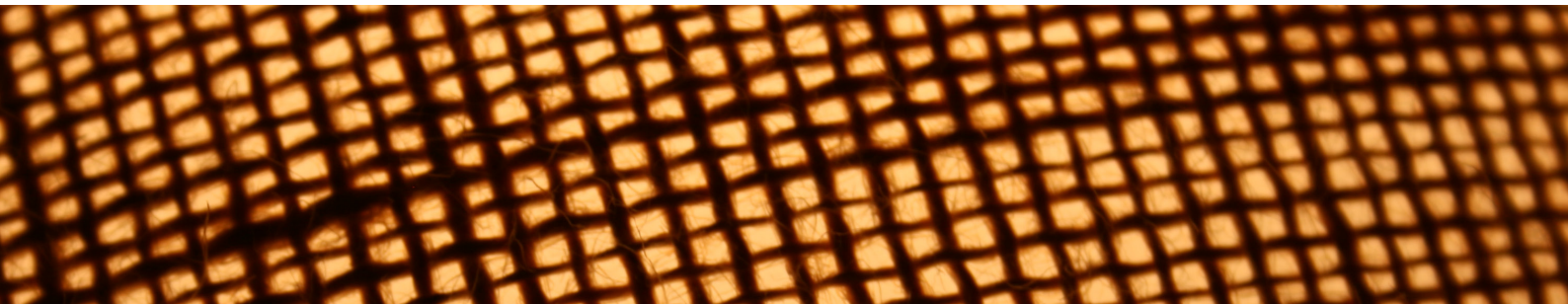
TecInTex aims at the development of truly textile-based advanced (electrical or optical) fibers incorporating sensors, signal transmission or other active components based on nanotechnology. A textile-based Near Infrared Spectroscopy fabric and an intelligent underwear for paraplegics demonstrate the functionality in a clinical setup.

**How the project differentiates from similar competition in the field**

Designing and manufacturing wearable sensors is a new field of study and their functionality has rarely been demonstrated in clinical environment until now. To the team's knowledge, wearable sensors have neither been used for prediction of pressure ulcer development nor for skeletal muscle (i.e. calf muscle) oxygenation measurement in clinical environment. Any success in prediction of such situations could improve the quality of life in paraplegics and subjects with high risk of Peripheral Vascular Disease (PVD).

**Quick summary of the project status and key results**

Functionalized e- and o-fibres have been tested in textile fabric. Including micron-submicron selective coating on metallized fibres. Humidity and pressure sensing functionalities have been demonstrated on textile fibers integrated into functional fabrics. Optical fibers for biosensing have been developed for pH and protease activity detection. A prototype has been designed and developed, including connections, electronics and signal processing. It is possible to monitor pH and protease activity with 6 optical fibres simultaneously (3 for pH and 3 for proteases). Sensorized fabrics were tested on body and on wound model. TFT circuits on plastic achieve cut-off frequency around 1 MHz without degradation after 1000 bending cycles. The components and technology for the NIRS demonstrator are approved for the textile integration and clinical testing.



## Success stories

Demonstration of pH sensing plastic optical fiber on wound simulator. Demonstration of smart underwear with sensors and wireless electronics. Platform for CSEM participation in European project SWAN-iCare.

Building up a strong consortium for a CTI project with the goal to produce luminous textiles for phototherapy. The consortium consists of a fibre producer, an embroidery company, a company focusing on optical devices for phototherapy and of a clinical partner.

Successfully measuring Oxygenation on the Gastrocnemius muscle of 10 healthy subjects using the newly developed, textile based NIRS system.

Collaboration with Swiss Paraplegic Center in Nottwil. Collaboration with Dr. Med. Anke Scheel from Swiss Paraplegics Center

Three PhD theses at ETH strongly related to TecInTex have been submitted and partly finalized in the last year.

The paper entitled "Flexible a-IGZO TFT amplifier fabricated on a free standing polyimide foil operating at 1.2 MHz while bent to a radius of 5 mm" has been accepted at the 2012 International Electronic Device Meeting, IEDM, the top conference in microelectronic devices.

**Presence in the media:**

- TTC - Le monde selon Johnson - 29.10.2012. Le tissu intelligent Le maillot de sport avec des fibres optiques et électrodes pour mesurer le rythme cardiaque. La technique est développée par le Centre de microtechnique de Neuchâtel. La fabricante de l'entreprise Smartex, Rita Paradiso, explique comment on utilise le T-shirt. Le centre CSEM a développé aussi des pansements intelligents. Explications de Stéphanie Pasche, CSEM
- TV (14.03.2013: SRF1; 17.03.2013: SF Info; 12.05.2013:3Sat): „Kunstfasern – leuchten, leiten, filtern"
- TV Einstein 12.09.2013

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L. Petti, P. Aguirre, N. Münzenrieder, G.A. Salvatore, C. Zysset, A. Frutiger, L. Büthe, C. Vogt and G. Tröster, Mechanically flexible vertically integrated a-IGZO thin-film transistors with 500 nm channel length fabricated on free standing plastic foil, accepted at IEDM 2013

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C. Zysset, T. Kinkeldei, N. Münzenrieder, L. Petti, G.A. Salvatore and G. Tröster, Combining electronics on flexible plastic strips with textiles, Textile Research Journal, 83, 11, 1130 - 1142, 2013

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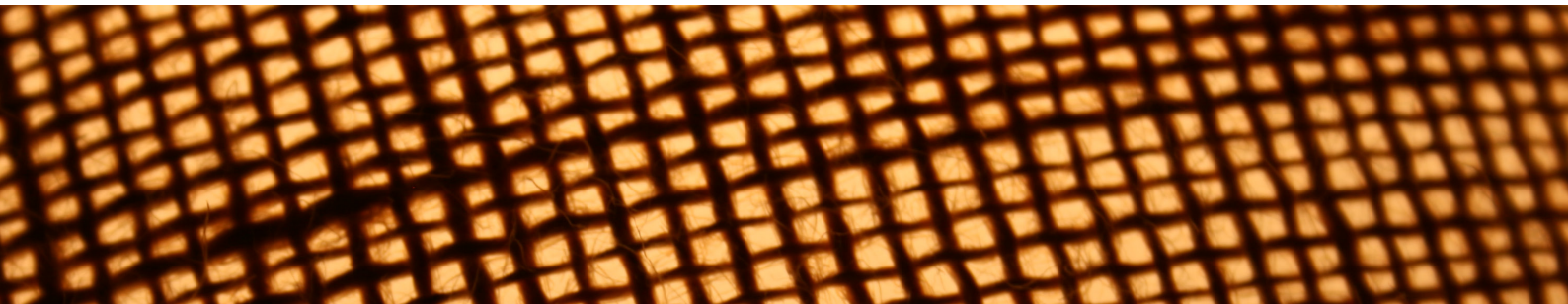

# X-Sense

## MONITORING ALPINE MASS MOVEMENTS AT MULTIPLE SCALES

Prof. Lothar Thiele, ETHZ

Dr. Jan Beutel, ETHZ

Prof. Alain Geiger, ETHZ

Dr. Stephan Gruber, UZH

Dr. Hugo Raetzo, FOEN

Dr. Tazio Strozzi, Gamma Remote Sensing

### What it's about…

***Investigating wireless sensing technology as well as associated models and methods towards a new scientific instrument for environmental sensing under extreme conditions in order to advance applications in science and society: geophysical research and early warning against natural hazards.***

### Context and project goals

In the context of climate change X-Sense investigates why mountain slopes get unstable with a focus on high-alpine terrain (permafrost). Here the consortium develops wireless measurement technology, integrates across various sensing dimensions, develops advanced processing and data fusion algorithms to better understand and forecast natural hazards.

### How the project differentiates from similar competition in the field

Few wireless sensor network projects have been demonstrated with real applications over a prolonged timespan. X-Sense is not only demonstrating the feasibility of such a technology and years of unattended lifetime in harsh environments but also significantly advancing applications in science for the benefit of society. By integrating multiple sensing dimensions with new models and methods, it is possible to gain understanding of the underlying geophysical processes on multiple scales and prepare the use in early warning scenarios.

### Quick summary of the project status and key results

Starting from initial conception and basic installations in the first years, the goals of the project have been reached in the final phase. In particular, the full pipeline from GPS and image sensors to the data-base servers has been established and thoroughly tested. New algorithms have been developed and applied that lead to high precision sensing, high data quality by means of network tomography and highly robust processing and communication in extreme environments. The sensor installations have been in operation in the Matter valley, Switzerland, for 4 years and produced several hundred million data packets: This continuous operation period as well as the corresponding data quality is unique. As a result, many new scientific results in the area of geoscience have been made possible. They help us get a better understanding of complex geophysical processes in permafrost regions and the destructive processes due to global warming. Currently, hardware and software are built and transferred to the Federal Office for the Environment for early warning purposes. Further field sites are envisioned for the next year.

In summary, it was shown that anticipation of future environmental states and risk benefits from environmental sensing at diverse modalities and scales, and from process modeling. Wireless Sensor Network Technology allows to quantify mountain phenomena, and can be used for safety critical applications in an hostile environment.

## Success stories

- Best paper award for Matthias Keller: The Problem Bit at DCOSS 2013. The paper describes the results concerning network tomography.
- The complete simulation framework GEOTop for model-based interpretation of acceleration/deceleration patterns of moving slopes in now in place.
- The GPS post-processing of the X-Sense stations is done automatically both in real-time and on post-processing basis. The latter is used for high precision determination of displacements (< 1cm accuracy) and velocities. These calculations are carried out in daily sequences and on selected stations in few-hours bits. Therefore, the whole data pipeline is automated, from sensor readings to processed and cleaned data.
- Continuous GPS positions allowed for describing and analyzing the short-term velocity variations of permafrost slope movements. Knowing the timing of acceleration or deceleration of slope movements helped to identify important controls and hence to increase the process understanding.
- Wirelessly controlled high resolution image sensors have been design and installed to allow for multi-mode and multi-scale location sensing. A recently acquired 1m resolution digital elevation model (BAFU) along with absolute camera orientation parameters has been used to relate each image point with absolute coordinates, thus allowing to properly scaling the estimated image displacements into metric quantities.
- The project gained quite a lot of public attention. Currently, hardware and software are built and transferred to the Federal Office for the Environment for early warning purposes. Further field sites have been installed this year together with other science partners, more are envisioned for the next year.

### Presence in the media:

Scientifica ('PermaSense - Naturgefahren im Gebirge'), Treffpunkt Science City (April 7, 2013), TCS, Natur.de ('Wenn der Berg rumpelt'), ETH Life, Walliser Bote, 20min.ch ('Bröckelnde Berghänge: GPS-Geräte sollen warnen'), Radio Rottu, Walliser Bote ('ETH-Forscher erkunden Permafrost im Mattertal'), ETH Globe ('Eavesdropping on the Matterhorn'), Tagesschau (SRF), LeMatin.ch, etc. For more details, see full report.

### Main publications


M. Woehrle, K. Lampka and L. Thiele, Segmented State Space Traversal for Conformance Testing of Cyber-Physical Systems, FORMATS 2011, LNCS 6919, Springer, Heidelberg, pages 193--208, September, 2011.

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