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swiss scientific initiative in health / security / environment systems

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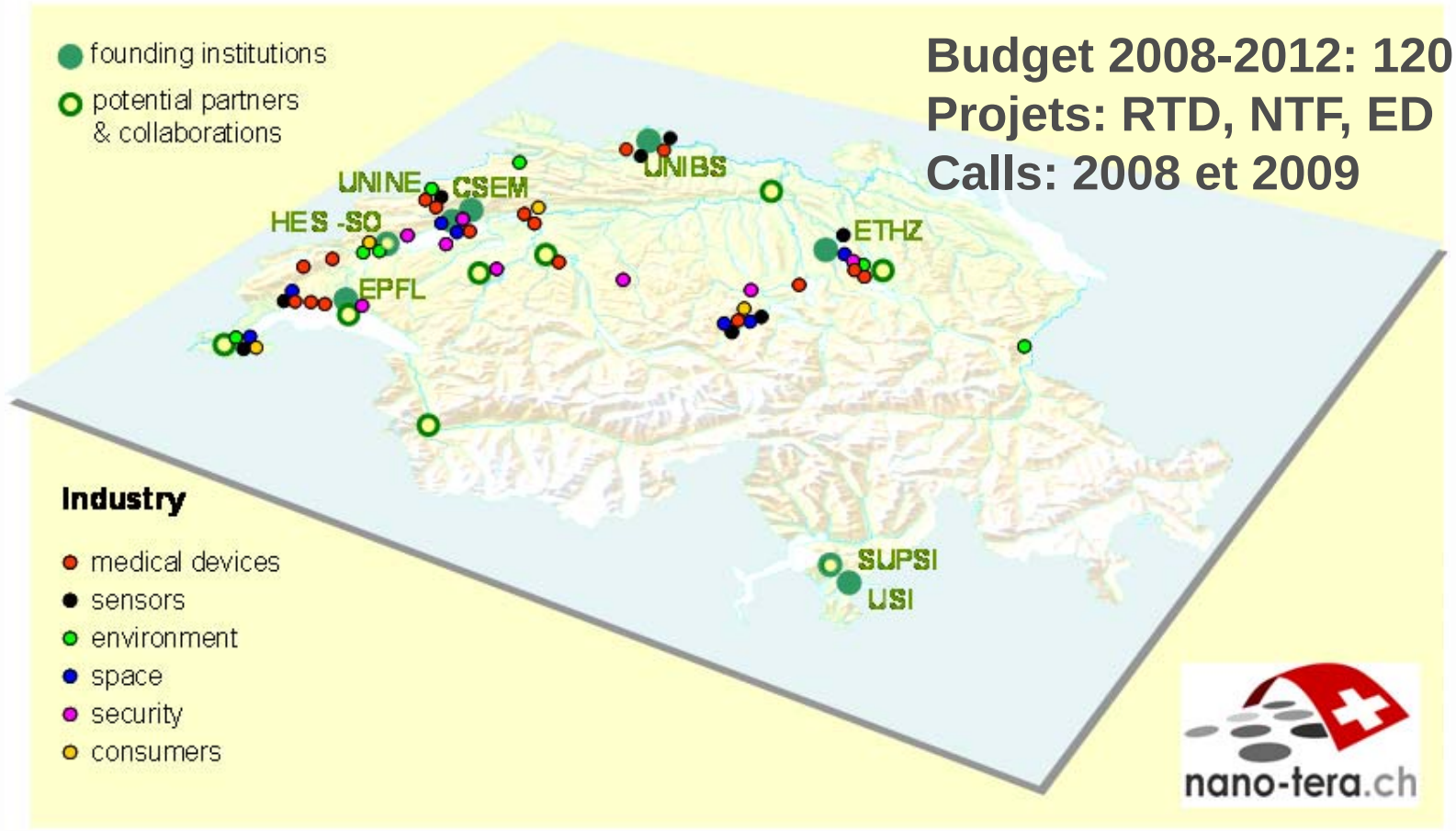
# Partners and collaborations




**Budget 2008-2012: 120MCHF**
**Projets: RTD, NTF, ED**
**Calls: 2008 et 2009**

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# Partner institutions

## Founding institutions

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Università della Svizzera italiana

UNI BASEL

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Université de Neuchâtel unine

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## Other participants

EMPA

PAUL SCHERRER INSTITUT PSI

fsrm

n|w Fachhochschule Nordwestschweiz

Hes·so Haute Ecole Spécialisée de Suisse occidentale Fachhochschule Westschweiz University of Applied Sciences Western Switzerland

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CHUV

ist

Swiss Paraplegic Centre

UniversitätsSpital Zürich

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SYMBIOS

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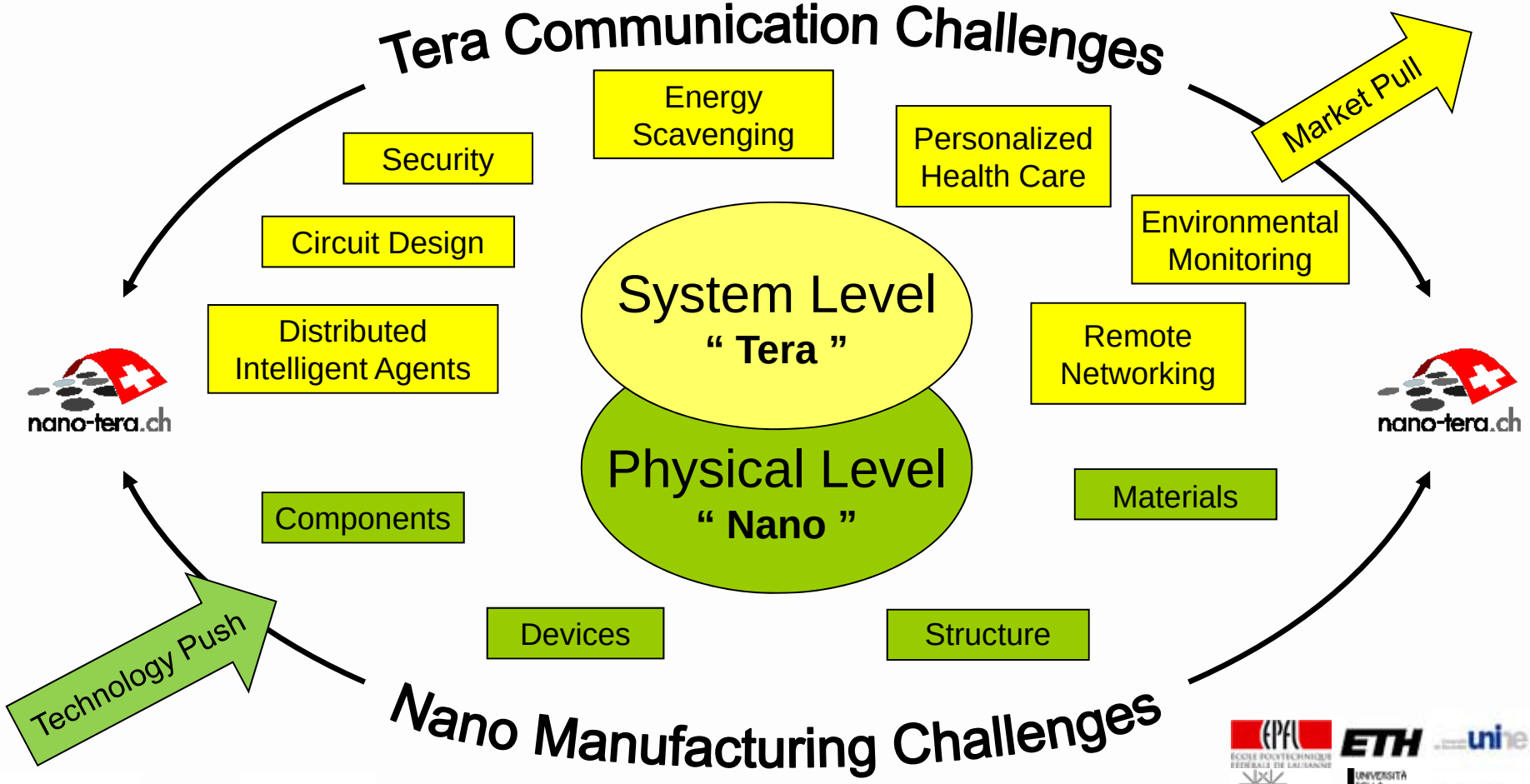
# Converging Challenges



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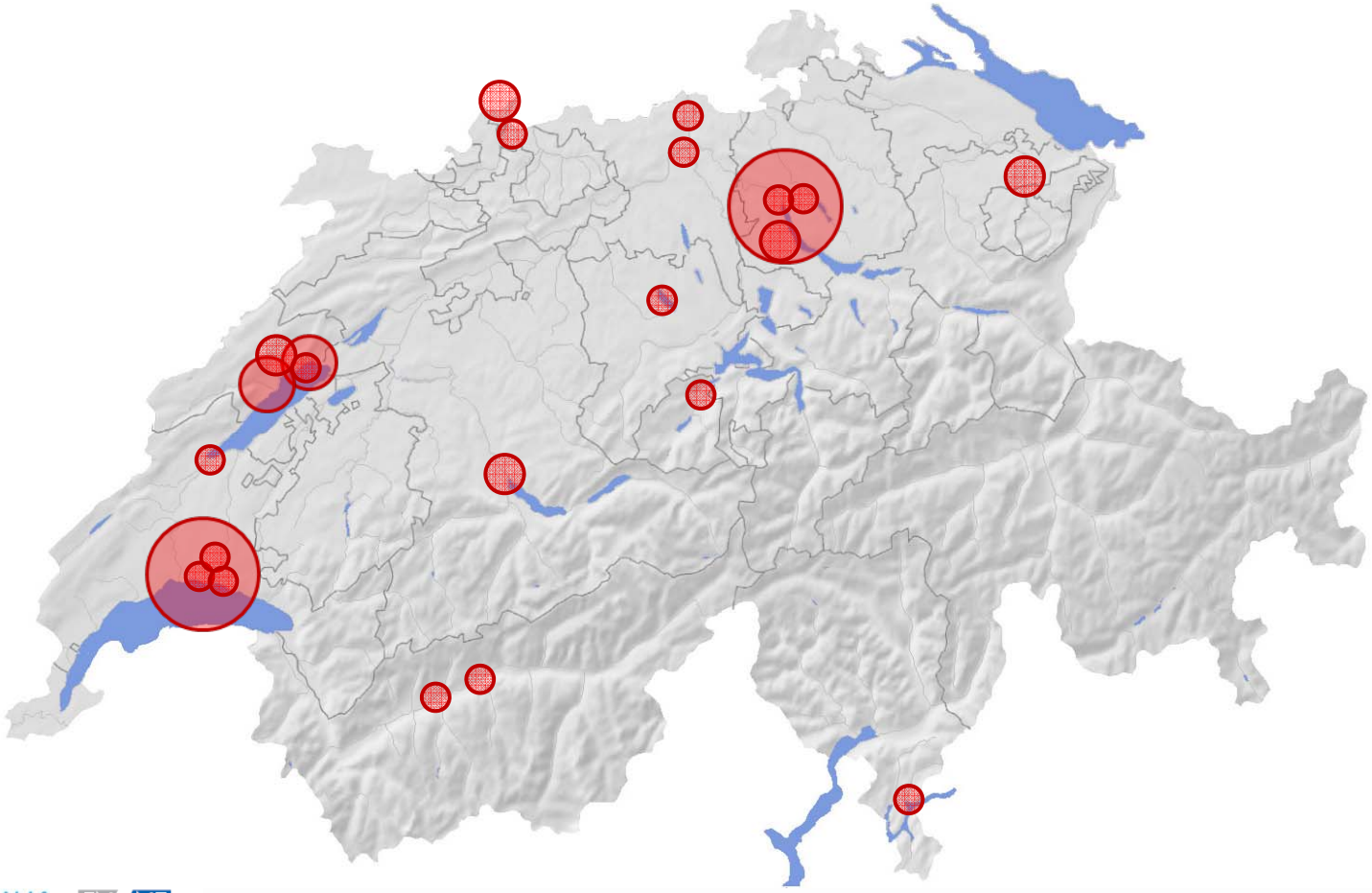
# Distribution of research groups



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# *Sensing platforms for health & environmental monitoring*

Various key elements…

- CNT electro-mechanical resonators
- Textile-integrated sensing
- ISFET sensing with silicon nanowires
- Living cells
- Optical absorption with VCSELs & QCLs

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# CabTuRes

## Low-power nano-sensors based on tunable CNT electro-mechanical resonators

*Christofer Hierold (ETHZ)*

- physics of carbon nanotubes
- engineering sciences in N/MEMS

➡ *novel CNT-based devices*: ultra-low power, miniaturized functional blocks for sensing & electronics

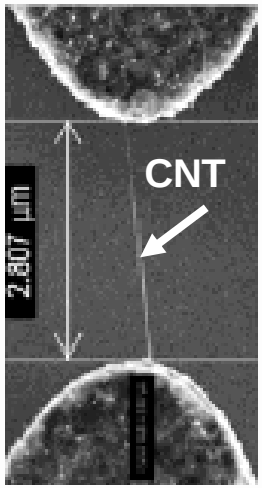
Using CNT-based nano electro-mechanical **resonators**:

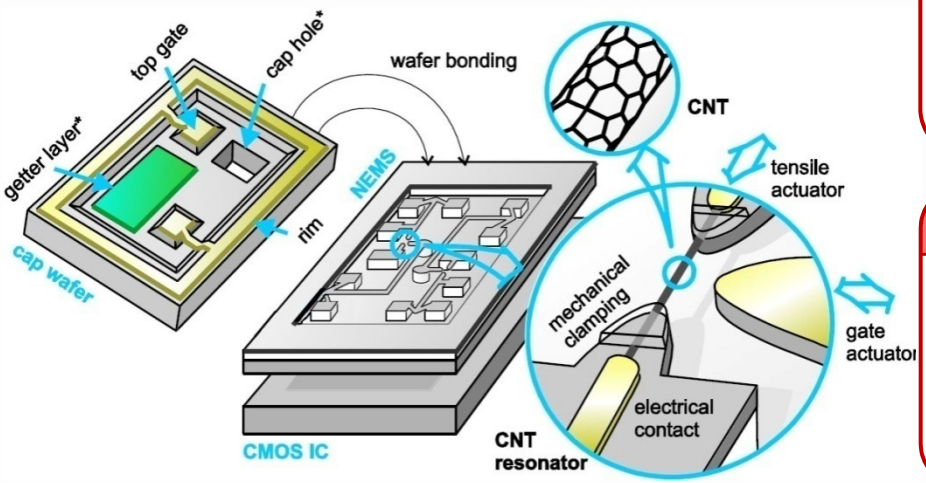
CNTs have small mass & high stiffness ➡ when doubly clamped: huge resonant frequencies reachable (>1GHz)

*Novelty*:

- better tuning via appropriate tensile actuators (uncontrolled chirality may not affect tunable CNT resonators)
- process flow allowing combination of MEMS with CNTs &CMOS ICs

➡ plethora of applications possible




### *Mass balances for sensing*

Mass loading creates shift in resonant frequency – with huge sensitivity to tiny mass changes

➡ Measure gas molecule densities
Weigh nano bodies (proteins, viruses…)

Strain also affects resonant frequencies

➡ Measure strain/stress/pressure…

### *Electronics applications*

CNTs: higher quality factors than L-C elements

➡ CNT resonators could be used as tunable RF voltage controlled oscillators

Multi-GHz range

➡ also good for NEMS filters and detectors

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# TecInTex

## Technology integration into textiles: empowering health

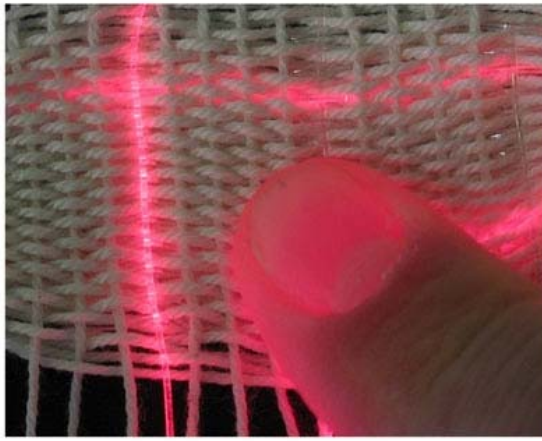
*Gerhard Tröster (ETHZ)*

Sensing capabilities close to the human body ➡ monitor activity, motion, health…

Incorporate built-in technological elements in our everyday textiles & clothes

Existing E-textiles: low processability, wearing comfort, washability…

➡ Goal: | get the crucial core modules to design & manufacture truly wearable functional clothes



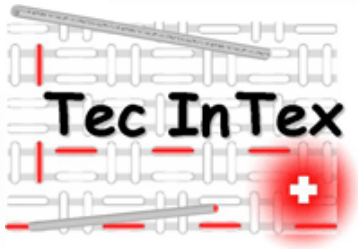
- electronic fibers ➡ point-to-point connection inside the fabrics
- optical fibers ➡ sensitive to changes in the contacting liquid env. (bio-sensing appl.)
- sensor yarns & stripes
- transducer between optical & electrical signals

### *Active near infrared spectroscopy sock*

Peripheral vascular disease affects 30% of adults

Early detection possible by near IR spectroscopy, but conventional sensors are cumbersome

➡ Light wearable system in sock to monitor tissue oxygenation continuously & non-invasively




### *Intelligent underwear for paraplegic people*

Pressure ulcers
big problem of paraplegic and bed ridden patients

➡ Build a comfortable device to detect the risk for pressure ulcers in order to enable preventive measures

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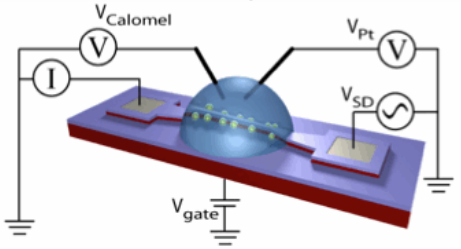
# NanowireSensor

Integrateable silicon nanowire sensor platform

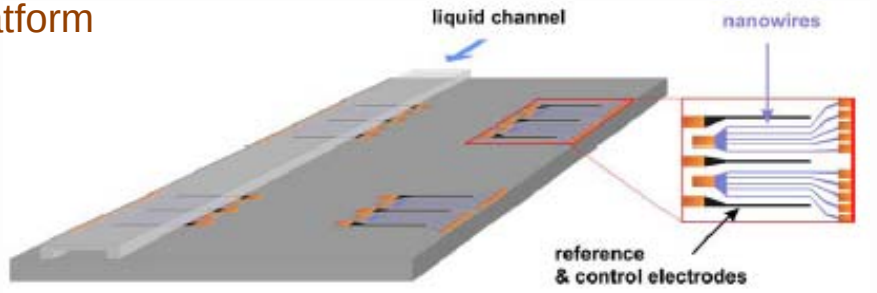
*Christian Schönenberger (UniBS)*

Sensor platform for the electronic detection of analytes in solution – modular, scalable & integrateable

- Technique without biochemical labeling
  (no risk to alter target molecules, cheaper & faster)
- No optical techniques which remain difficult to integrate at large-scale
- Differential readout capability with in situ references (to prevent mis-readings)
- Immediate or on-chip signal conditioning (to reduce noise)




➡ Ion-sensitive field-effect transistor sensor platform based on silicon nanowires to be integrated in a CMOS architecture




Progress needed: understanding of the sensing mechanisms and improved control

## *Personalized medicine*

Robust / flexible / cheap platform to grant effective diagnosis possibilities for healthcare specialists

Long-term vision: Embedded systems for constant health monitoring (diabetes, etc.)

## *Systems biology*

Quantitative detection of numerous substances in parallel at very low concentrations

For example: new insights into metabolic processes of cells, organisms and organs, etc.

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# LiveSense

## Cell-base autonomous biosensing microsystem

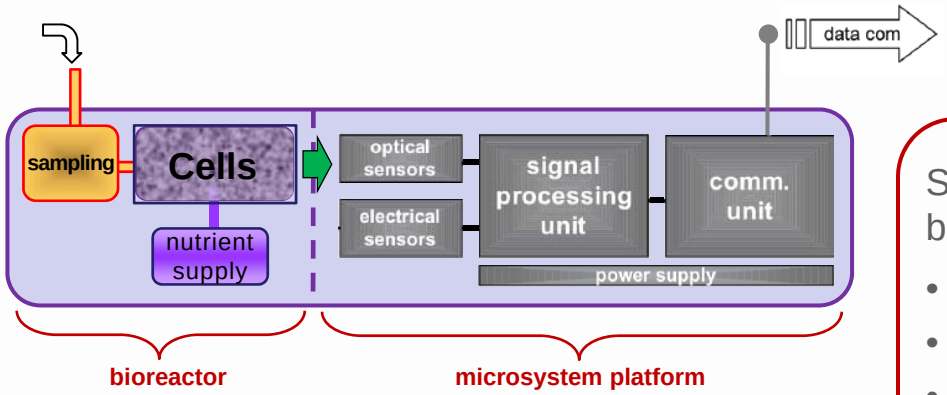
*Philippe Renaud (EPFL)*

Environmental monitoring – warning system for the health of a biotope

→ need a set of autonomous remote nodes able to locally collect samples and send information

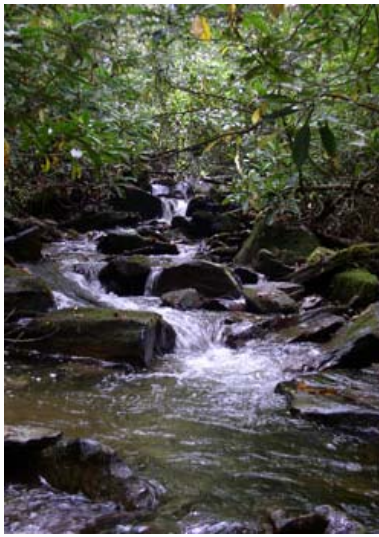
Cell-based biosensors provide a biologically relevant response to toxic compounds and mixtures


*canary used as «biosensor» in coalmines*




Strong interactions between partner teams:

- study of the cell models
- development of microbioreactor
- secondary sensors to detect the cell response
- integration of a demonstrator to be deployed in a river



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# IrSens

## Integrated sensing platform for gases and liquids in the near and mid-infrared range

*Jérôme Faist (ETHZ)*

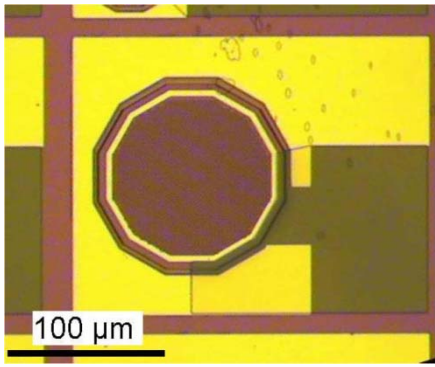
Sensing platform based on optical absorption

Principle: probing the vibrational frequencies of targeted molecules (near/mid-infrared range)

➡ unambiguous signature of the fluid investigated

- high sensitivity for both **gases** and **liquids**
- low price
- low power consumption

Semiconductor optical sources & detectors ➡ Vertical Cavity Surface Emitting Laser
Quantum Cascade Laser
Quantum Cascade Detector




### *Optical sensing in the gas phase*

Human breath analysis

QCLs as powerful light source in the mid-infrared

Detection of the helicobacter pylori with isotopic ratio measurements in exhaled $CO_2$

### *Optical sensing in the liquid phase*

Multi wavelength semiconductor laser source
(mid-infrared QCLs – near-infrared VCSELs)

- high sensitivity
- small sample volume needed

➡ Ideal for bio-medical applications

Detection of drugs & doping agents in human fluids

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# *Development of key technologies*

- 3D ICs with interlayer cooling
- Fluid-mediated self-assembly for N/MEMS
- Ultrafast semiconductor lasers

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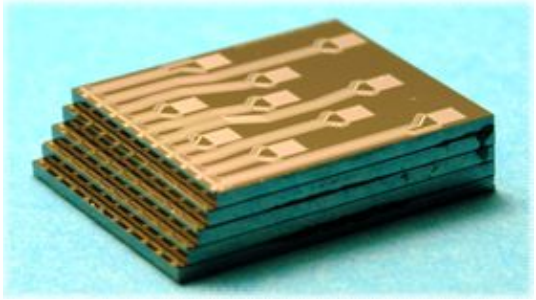
# CMOSAIC

## 3D stacked architectures with interlayer cooling

*John Thome (EPFL)*



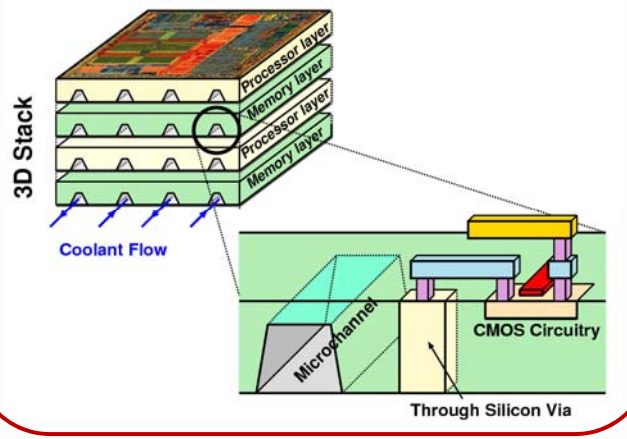
- 3D stacks of computer chips allow a huge functionality per unit volume
- Recent progress in the fabrication of through silicon vias

→ new ways for high density array interconnects between stacked processor & memory chips

**BUT heat needs to be removed !** [each layer dissipates 100-150 W/cm$^2$]

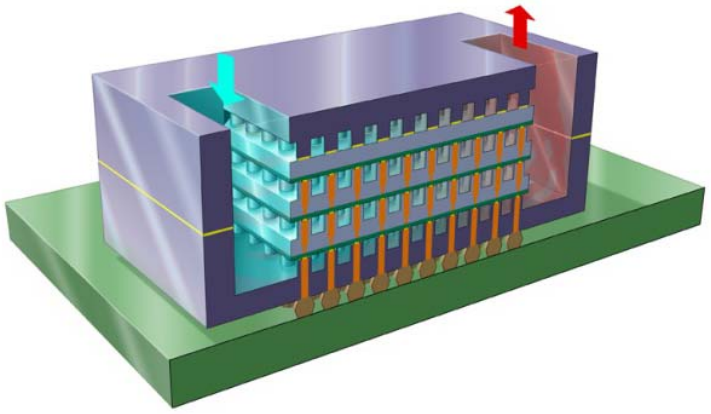
**These 3D integrated circuits need novel electro-thermal co-design**

Microchannels etched on back side of chips to circulate liquid coolant




Interdisciplinary problem approached at various levels:

- architecture
- microfabrication
- liquid cooling
- two-phase cooling
- nano-fluids



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# SelfSys

## Fluidic-mediated self-assembly for hybrid functional micro/nanosystems

*Juergen Brugger (EPFL)*

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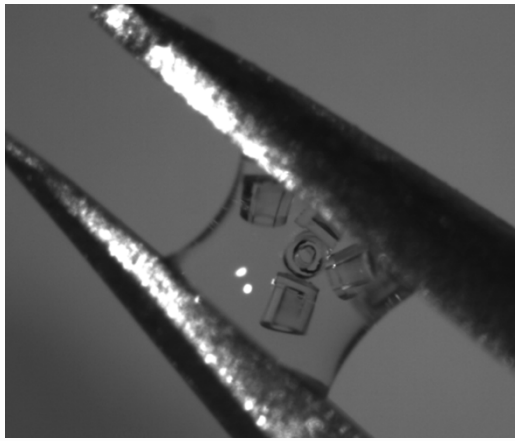
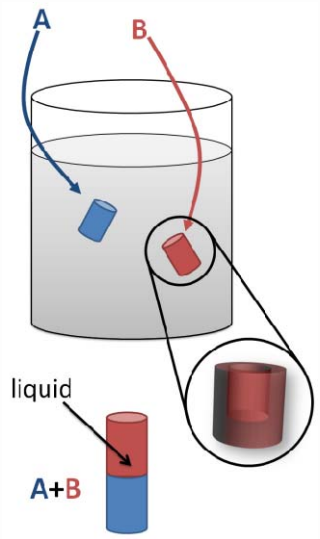
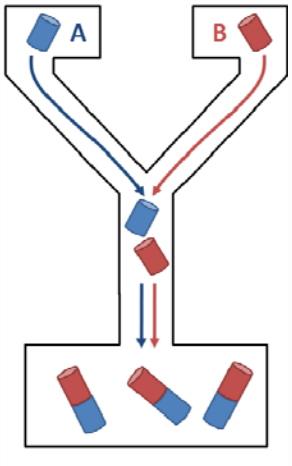
need to find **novel**, **low cost** processes to assemble and integrate complex micro-objects into large networks in a massively parallel manner



Self-assemble N/MEMS components as they are fully immersed in a liquid
➡ possibility to encapsulate the functional liquid

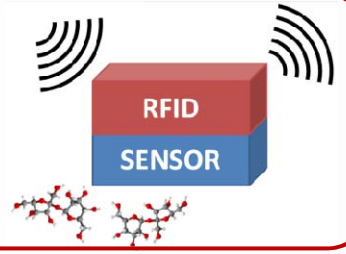
***Basic free self-assembly*** ***or…*** ***Alternate assembly in microfluidic channels***



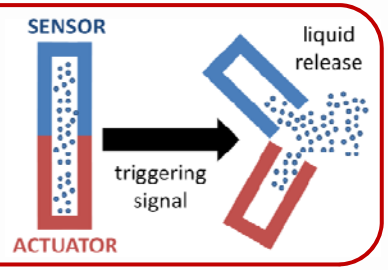




case studies

Assembly of MEMS to micronscale RFID tag for subsequent MEMS tracking




Assembly of liquid-containing micro-capsules that can be triggered for liquid release

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# MIXSEL

## Vertical integration of ultrafast semiconductor lasers for wafer-scale mass production

*Ursula Keller (ETHZ)*

Ultrashort pulse lasers: crucial for biomedical applications
(optical coherence tomography, photo-ablation of biological tissues…)

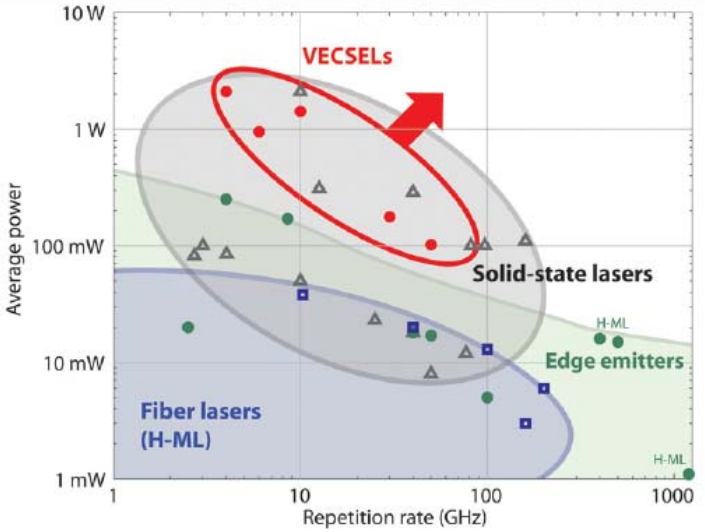
But need for affordable, integrable femtosecond laser modules

MIXSEL: mode-locked integrated external-cavity surface emitting laser

So far: only low-power optically pumped and picosecond regime MIXSELs

Goal: Demonstrate **optically** (>500mW) & **electrically** (>100mW) pumped MIXSELs in the **picosecond** and the **femtosecond** regime

- picosecond: *clocking applications…*
- femtosecond: *continuum generation, biomedical applications…*




Passive mode-locking requires saturable absorbers

Further development necessary:

For integration into MIXSELs and for femtosecond regime: exploration of quantum dot saturable absorbers

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# Applications

As shown above:

- Environmental monitoring / health of a biotope
- Measurements of tiny mass changes, stress & pressure
- Electronics applications (tunable RF voltage controlled oscillators, NEMS filters…)
- Health monitoring
- Sensing in the gas phase: bacteria detections
- Sensing in the liquid phase: detection of drugs & doping agents in human fluids

**But also…**

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# SImOS

## Smart implants for orthopaedics surgery

*Peter Ryser (EPFL)*

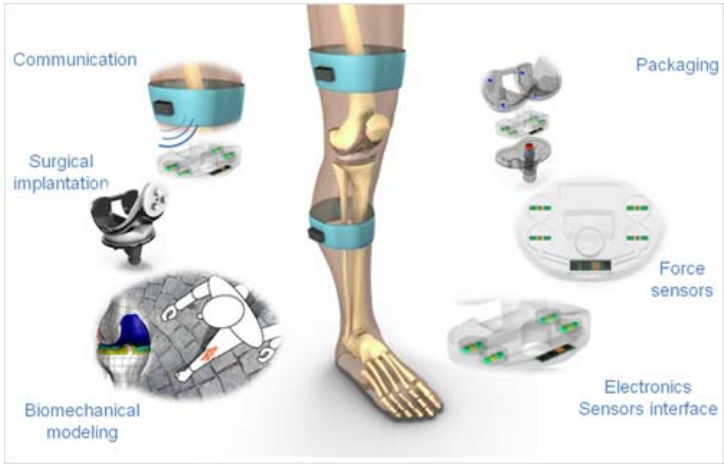
Joints implanted in EU & US: > 1 million/year

Expected to last 10-20 years… but frequent premature failure (~20% for people younger than 50)

➡ complex, costly & traumatic revision surgery needed

Goal: Design innovative tools (implanted & external) to monitor in vivo biomechanical parameters of joint prosthesis & orthopaedic implants

useful…
- during surgery – for alignment/positioning phase
- after surgery – to detect early migration
- during rehabilitation – to evaluate joint function




*Innovative features:*

### *Adjustable to all prostheses*

Currently: prostheses with implants must be custom-made

Resorting to nano-scale elements will not affect the mechanical properties

➡ System adaptable to any prosthesis for a better flexibility

### *With orientation sensors*

Beside force sensors, the prosthesis will also include orientation sensors.

Subtle combination of parameters from internal sensors (that need little power) and external sensors

### *Friction & loosening prevention*

More sensors can be included:

- Temperature sensors to measure friction and wear
- Accelerometers in order to prevent prothesis loosening

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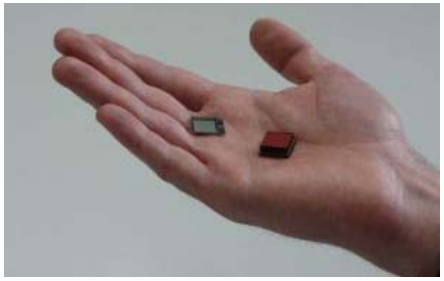
# Nexray

## Network of integrated miniaturized X-ray systems operating in complex environments

*Alex Dommann (CSEM)*



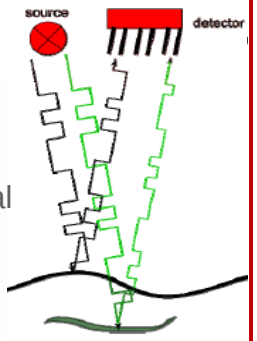
Development of **tera** X-ray networks made of **nano** components

- ***X-ray sources*** **– Based on carbon nanotube cold emitters**
  CNT dimensions ensure a large electrical field enhancement factor
  ➡ low threshold voltage for electron extraction
  Miniaturization of the whole source to 1 $mm^3$ only
- ***X-ray direct detectors*** **– Based on cystalline Ge absorption layers grown directly on CMOS sensor chip**
  Ge layer grown by low-energy-plasma-enhanced-vapour-deposition
  High resolution & high sensitivity, targeting single photon detection

### *X-ray time-of-flight measurements*

Intensity modulated X-rays emitted are partly reflected back *(Compton backscattering)*

Measurement of phase shift ➡ knowledge of reflection depth




Not achievable with conventional X-ray setups:

- Remittance of intensity modulated X-ray signal only possible with CNT based cold emitters
- Data-preprocessing needed at the pixel level: only possible with CMOS-based detectors

➡ Detection of buried landmines with knowledge of depth!

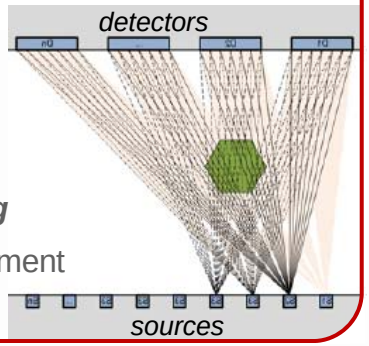
### *Tomographic imaging*

Computer tomography is a crucial tool in modern medicine
Now: sources & detectors are rotated mechanically around the body

In this project:
Both the X-ray detector ***and*** the X-ray source are pixelated

➡ this combination provides new imaging capabilites,
e.g. ***static tomographic imaging***

CT achieved by geometrical arrangement instead of mechanical movement

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# Nano-Tera Focused projects

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# ULP-Logic

## Sub-threshold source-coupled logic circuits for ultra low power applications

*Yusuf Leblebici (EPFL)*

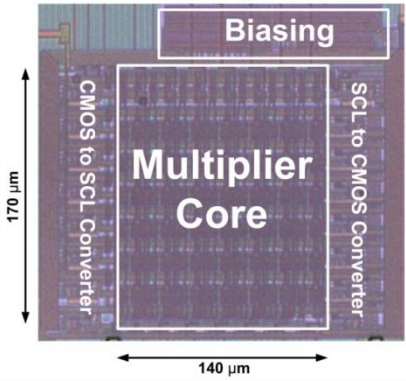
Ultra-low power digital systems crucial in many modern applications

- mobile systems
- sensor networks
- implanted biomedical systems

Logic circuits in sub-threshold regime an important challenge!

In sub-threshold MOS devices… supply voltage ↘ → power dissipation ↘ ☺
speed of operation ↘ ☹

Moreover, power consumption is difficult to control



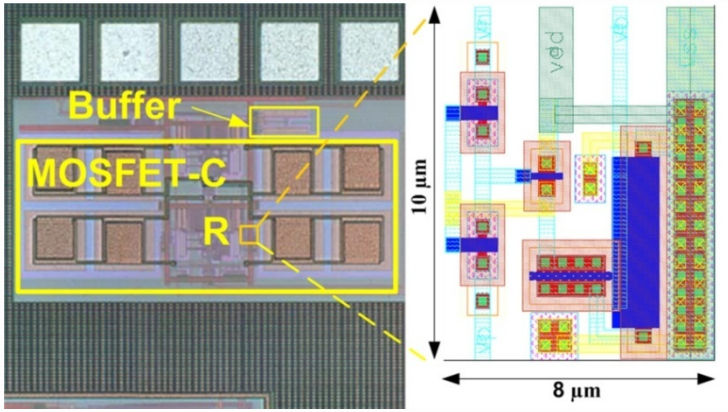

*(8x8) bit Cary-Save adder multiplier based on STSCL topology*

Here: sub-threshold **source-coupled logic** circuits as a new family of ultra-low power circuits capable of operating at relatively high frequencies

Linear adjustment of power consumption and speed of operation over a wide range

→ Large potential for implementing ultra low power digital systems!

Preliminary results on ST-SCL gate: power-delay product < 1 fJ




*Ultra-low-power MOSFET-C filter with a wide tuning range*

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# PMD-Program

## A programmable, universally applicable microfluidic platform

*Sebastian Maerkl (EPFL)*

Current micro-fluidics platforms:

- usually designed for one single purpose
- costly to design and implement
- require considerable in-depth knowledge

⇔ [Application-Specific Integrated Circuits in the semiconductor industry]

➡ Goal here: create **programmable micro-fluidics devices**: not hard-wired, can be custom programmed through software to perform various tasks

⇔ [Equivalent of Field Programmable Gate Arrays]

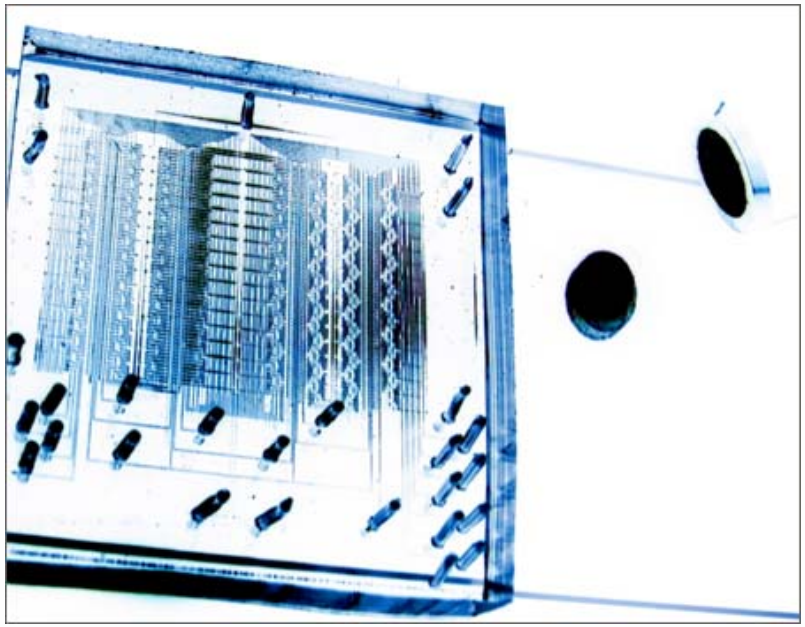
Techniques:

- multi-layer soft-lithography
- microfluidic large-scale integration

Easier integration of technologies, especially micro/nano sensors with fluidic components (human diagnostics, etc.)

Near-universal applicability & modularity

➡ huge commercial potential



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*Thanks for your attention !*