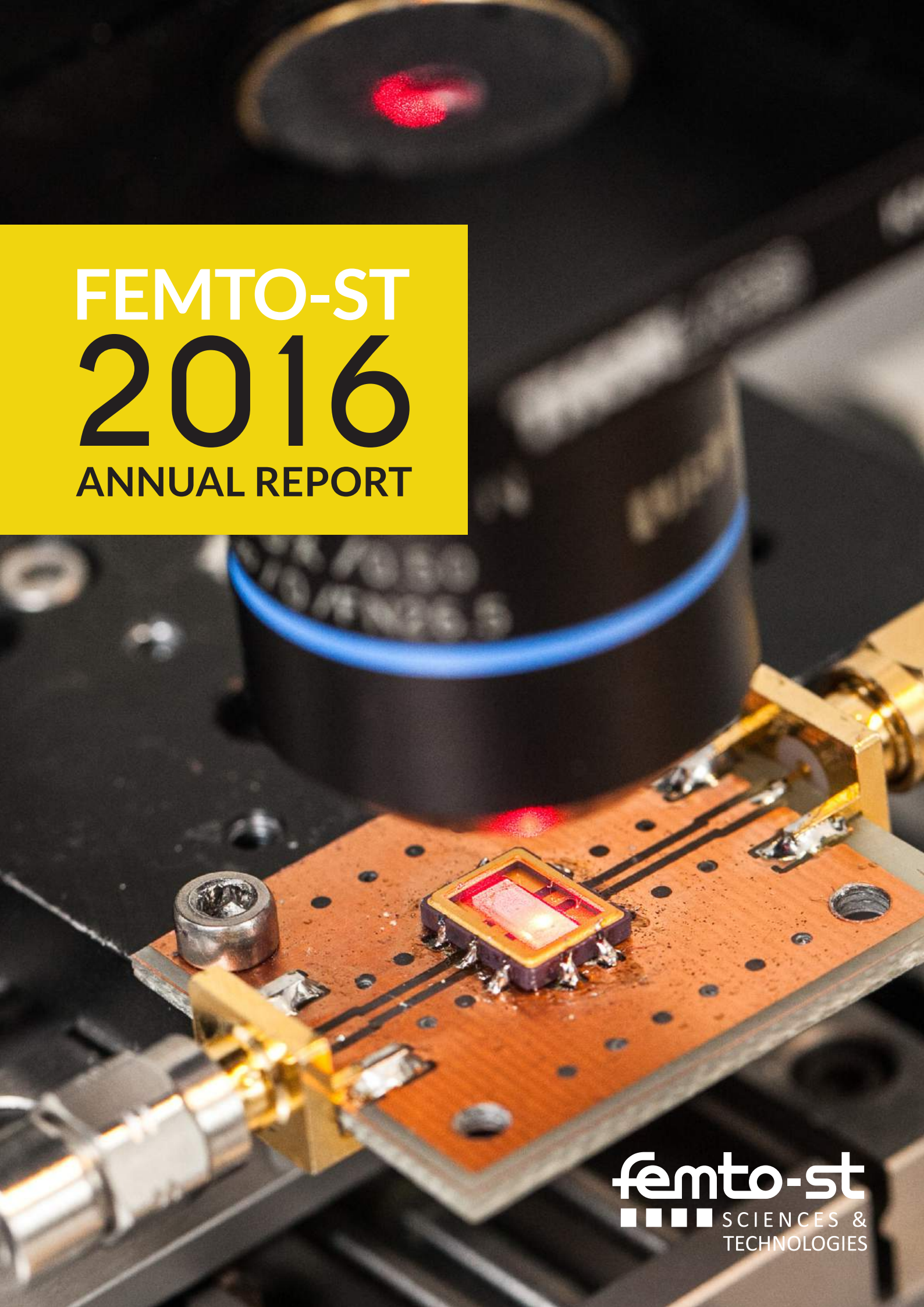


FEMTO-ST
2016
ANNUAL REPORT

femto-st
SCIENCES & TECHNOLOGIES

FEMTO-ST, a joint Research Institute from :

members of

FOREWORD

Cultivating innovation, from basic research to industrial partnership and spin-offs, developing micro and nano technologies, increasing the density of functions, integrating intelligence, for the engineering of components and systems with optimized performances.

Dear Reader,

This document aims at presenting a brief overview and examples of the scientific and technological activities carried out at the FEMTO-ST institute during 2016.

FEMTO-ST comprises 7 scientific departments with a total of over 750 members employed by four different public research and higher education institutions (University of Franche-Comté, CNRS, National Engineering Institute of Mechanics and Microtechnology, Technology University of Belfort-Montbéliard). Our work covers many different themes within the broad discipline of engineering science, from fundamentals to applications, and is structured around a strong interdisciplinary environment including robotics & automation, information science, energy, applied mechanics, micro-nano-sciences and systems, optics, RF and microwave metrology.

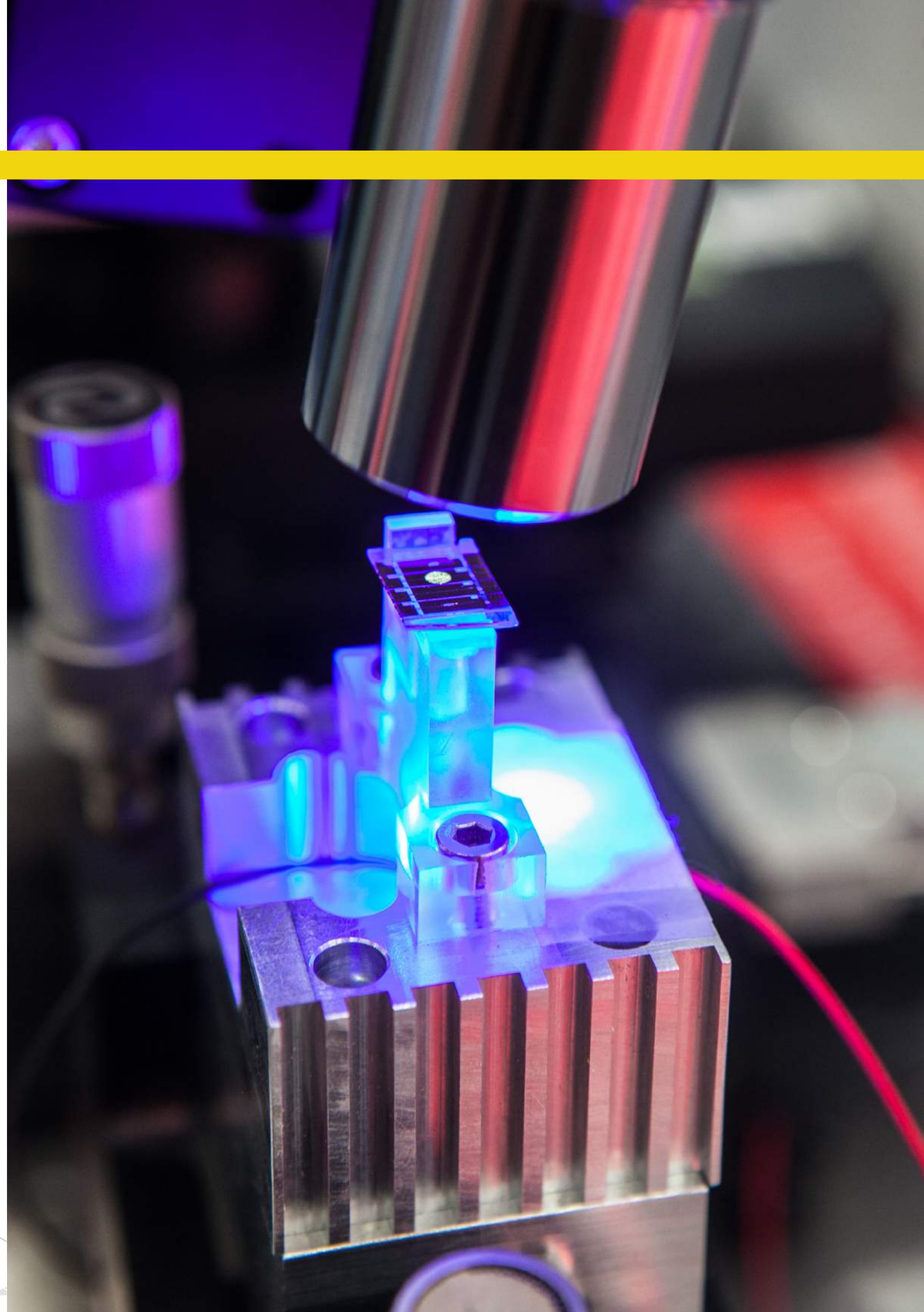
Although it is impossible for a report such as this to be exhaustive, we hope that you will be able to see the richness of our work through the examples that we have highlighted. We have tried to stress in particular the novelty, diversity and interdisciplinarity of our research topics, as well as our technological expertise and societal impact.

A further important development in 2016 was the five-year formal evaluation of FEMTO-ST which took place as part of the regular programme of national French public research institute evaluations. It is important in this Foreword to highlight the extremely positive conclusion of the international evaluation committee which recognized that the excellence in the research at FEMTO-ST is the consequence of the professional and passionate people working in our institute. I would like to thank all members of FEMTO-ST for their continued commitment to our goals.

I hope you will enjoy reading this annual report 2016, and that it will allow you to discover with interest the fascinating science we are trying to create every day at FEMTO-ST. My wish is that this will contribute to stimulating new and fruitful interactions, and it would be a great pleasure to work with you in the future.

Laurent LARGER
Director of FEMTO-ST Institute
laurent.larger@femto-st.fr

CONTENT



FRANÇOIS COURVOISIER IS AWARDED WITH THE AIMÉ COTTON PRIZE

The 2015 Aimé Cotton prize of the French Physical Society (SFP) has been awarded on 4th July 2016 to François Courvoisier for "his research in ultrafast optics in the linear and nonlinear regimes and its applications to laser ablation, particularly for experimental demonstrations of "non-diffracting" and "accelerating" beams and their development as novel tools for laser micro and nano machining". This prize is awarded every year to a young physicist in the field of molecular and atomic physics and optical physics and whose research is particularly innovative. François Courvoisier and his team have developed at FEMTO-ST a new research topic on ultrafast laser materials processing, which they placed at the frontiers of optics, plasmas and materials, with the objective of generating cutting-edge technologies and processes. The innovative point of view has been to use and develop specific "propagation-invariant" laser beam shapes to deposit extremely high energy densities in the bulk of materials such as glass. This generates powerful nanoscale laser ablation by extremely controlled sub-micron explosions that reach multi-megabars and allow for high speed dicing and cleaving of transparent materials.

Particular aspects of the awarded research are, first the experimental development of "nondiffracting" beams that deposit energy on highly focused but extremely long distances and create ultra-high aspect ratio nano-channels in dielectrics with just a single laser pulse; and second, the development of arbitrary curved beams in the non-paraxial regime that allow for cutting materials with curved edges. These two aspects were breakthroughs in the field of laser materials processing.

This research has been patented and the team works in close collaboration with FEMTO-Engineering for industrial transfer. Fundamental aspects of the research are continued within an ERC consolidator project PULSAR obtained in December 2015.

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Contact
François Courvoisier - francois.courvoisier@femto-st.fr

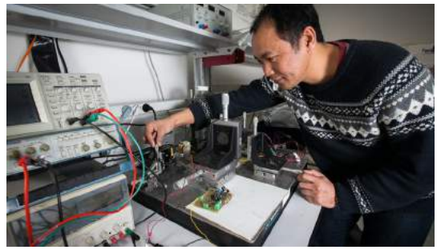
MICKY RAKOTONDRABE, RECIPIENT OF THE BIG ON SMALL 2016 AWARD

The "Big on Small" award recognizes a young researcher (less than 40yo) for her/his excellent performance and international visibility in the topics of manipulation, automation and robotics at small scales. Every year, a laureate is announced during the IEEE International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS, http://marss-conference.org/).

Micky Rakotondrabe, recipient of the Big on Small 2016 award, has been an Associate Professor at the University of Franche-Comté since 2007 and leader of the Control & Design research group of FEMTO-ST since 2015. His work deals with the development of micromechatronic systems and their automation in order to allow extremely precise and highly dynamic positioning tasks at small scales. He focuses his activities on piezoelectric actuators as a basic element of micromechatronic systems. These actuators uniquely offer both nanometric resolution, in excess of 1kHz of bandwidth, and a high force density. Furthermore, piezoelectric actuators are easy to integrate and to exploit because of their electrical input energy which is available almost everywhere.

However, most micromechatronic systems in general are known to exhibit nonlinear phenomena, badly damped vibrations and high sensitivity to the environment such as temperature variation. These characteristics could strongly affect the final precision or even the stability of the actuators and could only be counterbalanced by advanced control strategies. With this in mind, Micky Rakotondrabe and his team have developed original control methodologies based on robust and optimal feedback techniques as well as on low cost and highly integrated feedforward techniques.

This work has long-term impacts in various applications: allowing high speed and high precision manipulation and assembly of micrometric artificial objects such as watch components; increasing the bandwidth of images scanning with atomic force microscopes; increasing the speed and the resolution (and thus the storage capacity) of hard disk drive head.



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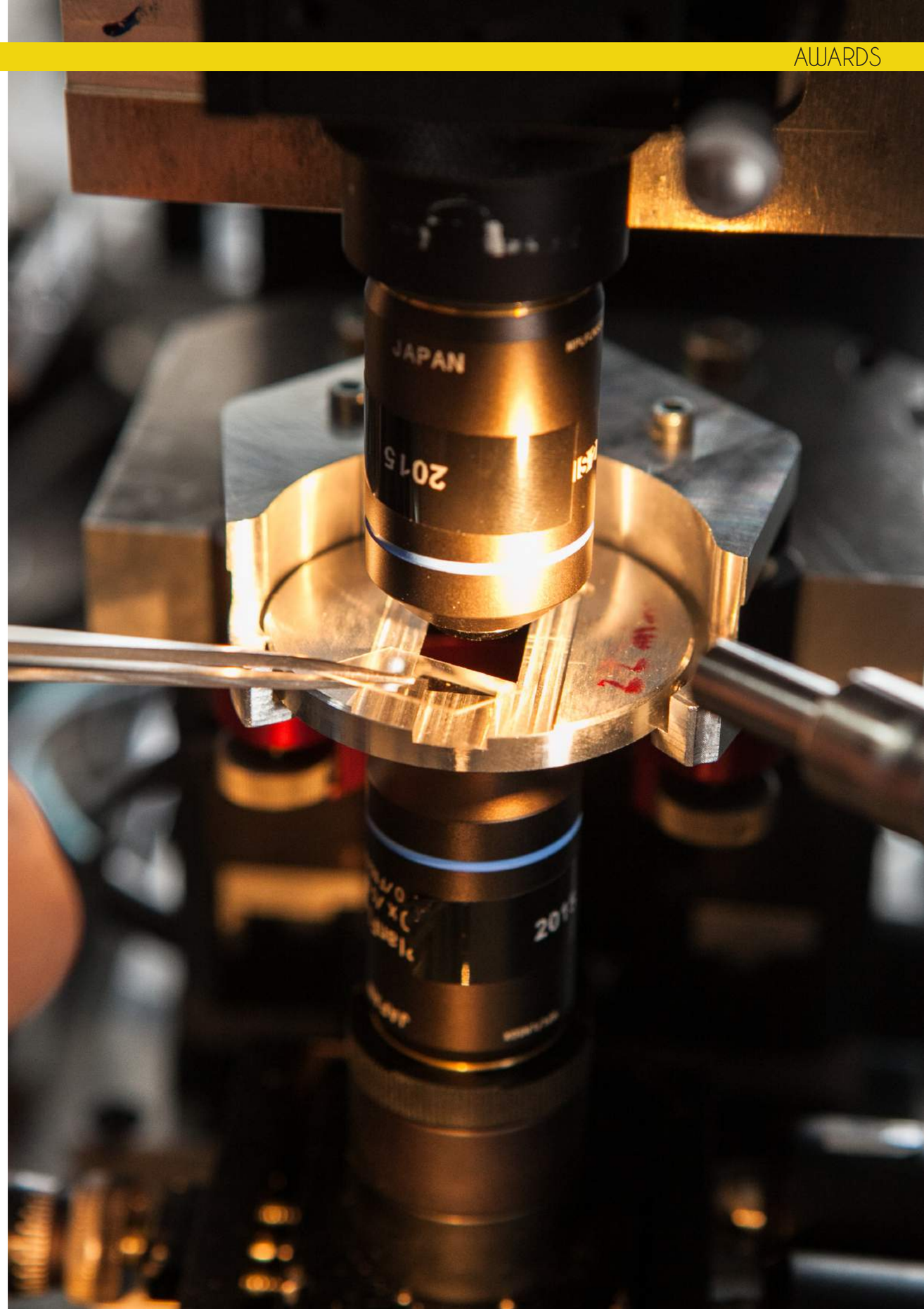
Contact
Micky Rakotondrabe - mrakoton@femto-st.fr



"ROBUST SMART PERIODIC TRUSS" BEST STUDENT PAPER AWARD

for the paper untitled “Robust Smart Periodic Truss” by L. Rodrigues Cunha at ISMA/USD 2016 (International Conference on Uncertainty in Structural Dynamics)

Leandro Rodrigues Cunha is a joint PhD student between Federal University of Uberlândia (Brazil) and FEMTO-ST. He has been awarded with the Best Student Paper Award during ISMA/USD 2016 conference in Leuven (Belgium).
His work is related to smart and periodic structures, which have recently received the attention of structural engineering researchers by virtue of their great potential. They offer some powerful properties like smart structures' adaptivity and periodic structures' ability to operate as mechanical filters. The design of the unit cell, which is repeated to obtain the periodic structure, directly provides dynamic properties with frequency bands in which no wave can propagate, meaning that the vibrations are filtered out. The efficiency of these so-called band gaps can be enhanced by including smart components in the base structure, such as piezoelectric devices connected to electronic circuits. The structure of interest is a periodic truss including piezoelectric stack actuators connected to resonant (resistor-inductor) shunt circuits. The passive electronic circuit is chosen to enhance the filtering effect. However, when the structure is manufactured, uncertainties occur in the geometry and thus in the properties of the system. It then becomes necessary to consider them to guarantee robustness ensuring minimal risk and satisfactory attenuation performances. A dedicated approach has been developed for estimating the impact of uncertainties on the performances of the system.

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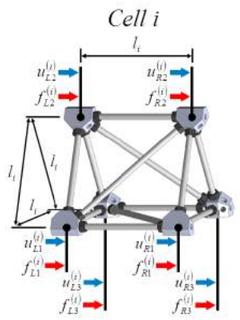

3D truss unit cell ; A chain of such cells forms the finite model

Contact :
Leandro Rodrigues Cunha - leandro.rodrigues@femto-st.fr

VINCENT LAUDE RECEIVES THE 2016 IEEE CARL HELLMUTH HERTZ AWARD

The IEEE Carl Hellmuth Hertz Ultrasonics Award is delivered annually by the IEEE Ultrasonics, Ferroelectrics, and Frequency Control (UFFC) society. It is intended for primary investigators that have contributed to the field of ultrasonics. Vincent Laude was presented with the award during the IEEE Ultrasonics Symposium in Tours, France, on September 19, 2016. The citation reads "For substantial contributions to the physics of phononic crystals and of the interaction of sound and light".
According to the IEEE/UFFC society website, “the award candidate has an excellent track record in terms of scholarly publications, technical reports and/or inventions/patents. The award is intended to recognize the investigators for their outstanding mid-career achievements and for promoting the field of Ultrasonics. This award was named for Carl Hellmuth Hertz to honor his pivotal role as both a researcher and as an advisor to others working in the field of medical diagnostic ultrasound imaging. The award is administrated by the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society.”
http://www.ieee-uffc.org/ultrasonics/awards-hertz.asp

Vincent Laude is a CNRS research director and a member at the MN2S department of FEMTO-ST. His research interests are in the propagation of elastic and acoustic waves in micro- and nano-structures, and especially in phononic crystals. These artificial periodic materials find applications for vibration and sound insulation, or wireless communications. Vincent is also very active in the field of the interactions of light and sound. He is the author of the monography « Phononic crystals: Artificial Crystals for Sonic, Acoustic, and Elastic Waves » that was published in 2015 and has authored more than 120 research papers in international peer-reviewed journals. He was the MN2S director from 2006 to 2009, and still acts as deputy-director of this FEMTO-ST department.

Presentation of the award by the Award Committee representatives and the President of the IEEE UFFC society.

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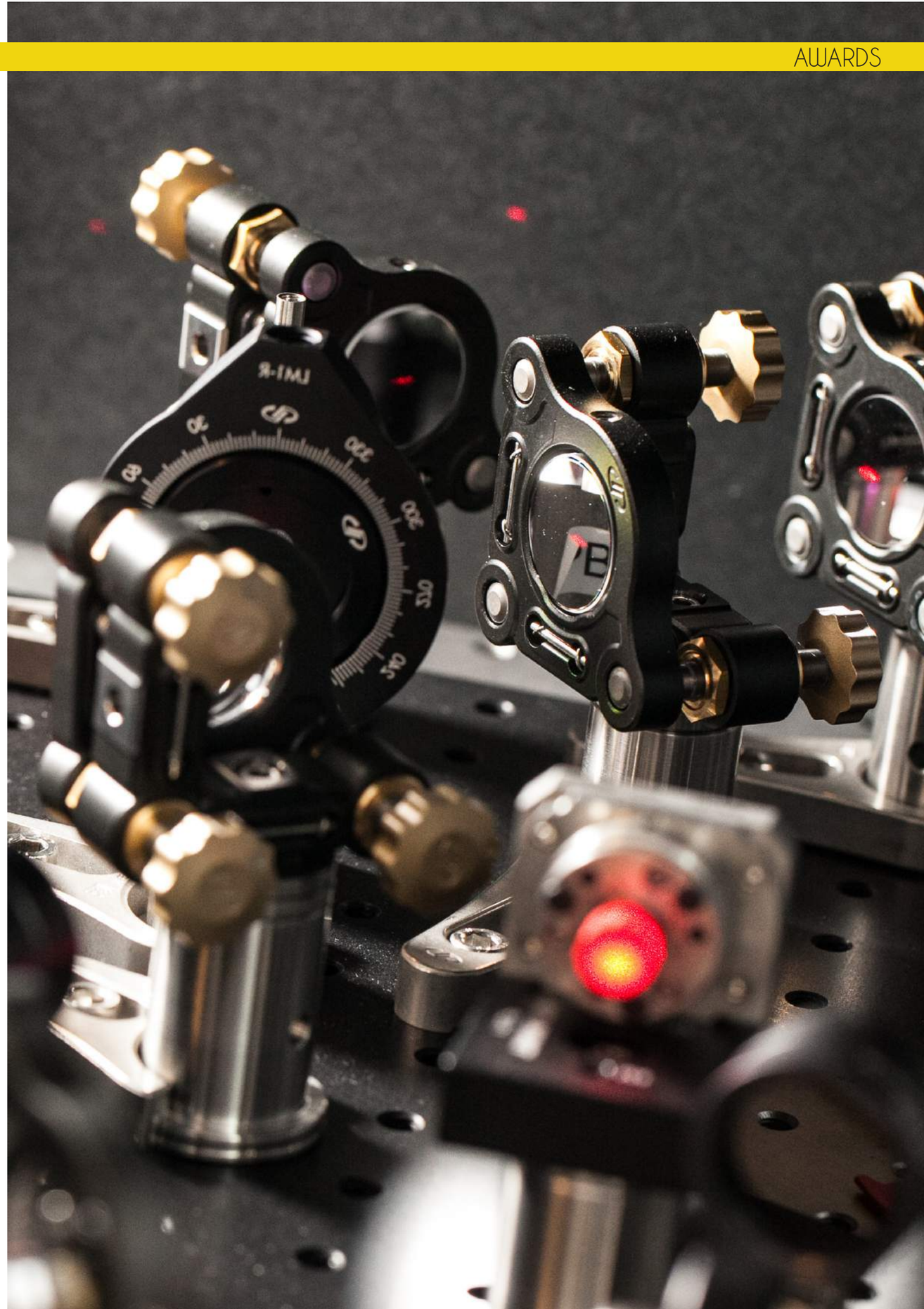
Contact
Vincent Laude -vincent.laude@femto-st.fr



TOP-SPEED CONVOLUTION AND MEDIAN FILTERS

Median filters and most convolution filters are amongst the most widely used operators in the field of signal processing.
Until recently, both of these filters used to be considered as standalone operators, essentially for noise reduction purposes.
Currently, however, the median filter is almost exclusively used as a preprocessing operator within more complex signal manipulation sequences.
Due to its linearity and versatility, the convolution filter has always been taken as a kind of swiss knife within a wider range of applications. Recently, it has become even more popular, as prevailing deep learning solutions are based on convolutional neural networks that involve a huge amount of convolution computations performed on Graphical Processing Units (GPUs).
The DISC group have proposed a new way of implementing median and convolution filters on GPUs that has broken the so far prevailing paradigm of shared memory usage and allowed optimal use of the different memory areas and cache mechanisms. Overall performances have proved significantly faster than all existing implementations, at least by one order of magnitude. In addition, both small-size median and convolution filters (3x3) have proved capable of throughput values above 90 % of the maximum throughput value allowed by hardware (Nvidia GPUs), and are thus able to process over 26 and 44 billion pixels per second respectively.
The illustration below shows how GPUs can achieve high processing speeds by running many execution threads in parallel. In this example of shot-noise reduction by means of a median filter, the input image (left hand side) is split into several regions like the blue-colored one. Each region is processed by one block of individual threads (256 threads in this example), which actually computes from 1 to 16 output pixel values.
Eventually, each region is written at the right place in the output image (right hand side).

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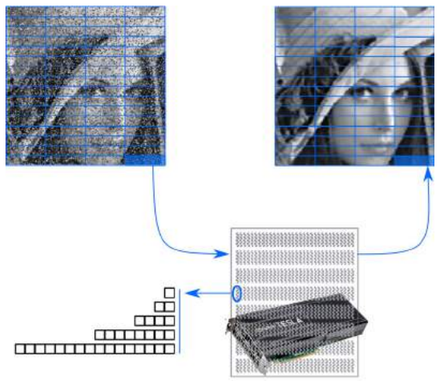
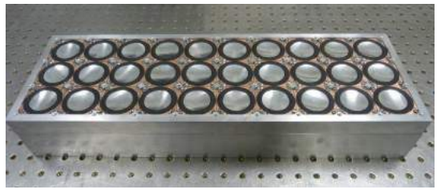


Contact
Gilles Perrot - gilles.perrot@femto-st.fr

ACTIVE METASURFACES FOR ACOUSTIC CONTROL IN DUCTS WITH AIR FLOW

The issue of noise and vibration still remains a subject of intensive research in academia and a subject of strong impact in the socio-economic world. Indeed, noise is a serious form of environmental pollution believed to affect the lives of hundreds of millions of citizens. In particular, it can be a determining factor in the transport industry (air, road and rail), civil engineering infrastructures, industrial machinery, etc. The prohibitive cost of the consequences of noise and vibration can dramatically affect the competitiveness of European industry. Improved technologies are required to meet current and incoming stringent international regulations.
In the context of ENOVAL project (ENgine mOdule VALidators, see http://www.enoval.eu), FEMTO-ST and EPFL have been asked by Safran Nacelles to propose a new active concept for controlling acoustic waves propagating in ducts. This system consists of a set of distributed cells on the boundary of the duct, with no impact on the flow itself. Each cell is composed by 4 microphones, one loudspeaker and the dedicated electronics allowing for an increased acoustic transmission loss up to 15 dB at Mach 0.15. Such a performance is much more than the one achievable with passive treatments in equivalent volumes, and it comes with the capability of being adaptive in frequency, allowing active tracking of the main components of the noise spectrum generated by the engine.
Starting from full-modelling (acoustic duct, loudspeakers and control algorithm), the system has been optimized, manufactured and validated. Flow tests have been conducted in the NLR (Netherland) facilities used for acoustic characterization of liners used in aircraft nacelles. The system is fully integrated, requiring only a power input, opening the way to various applications where noise has to be accurately controlled.



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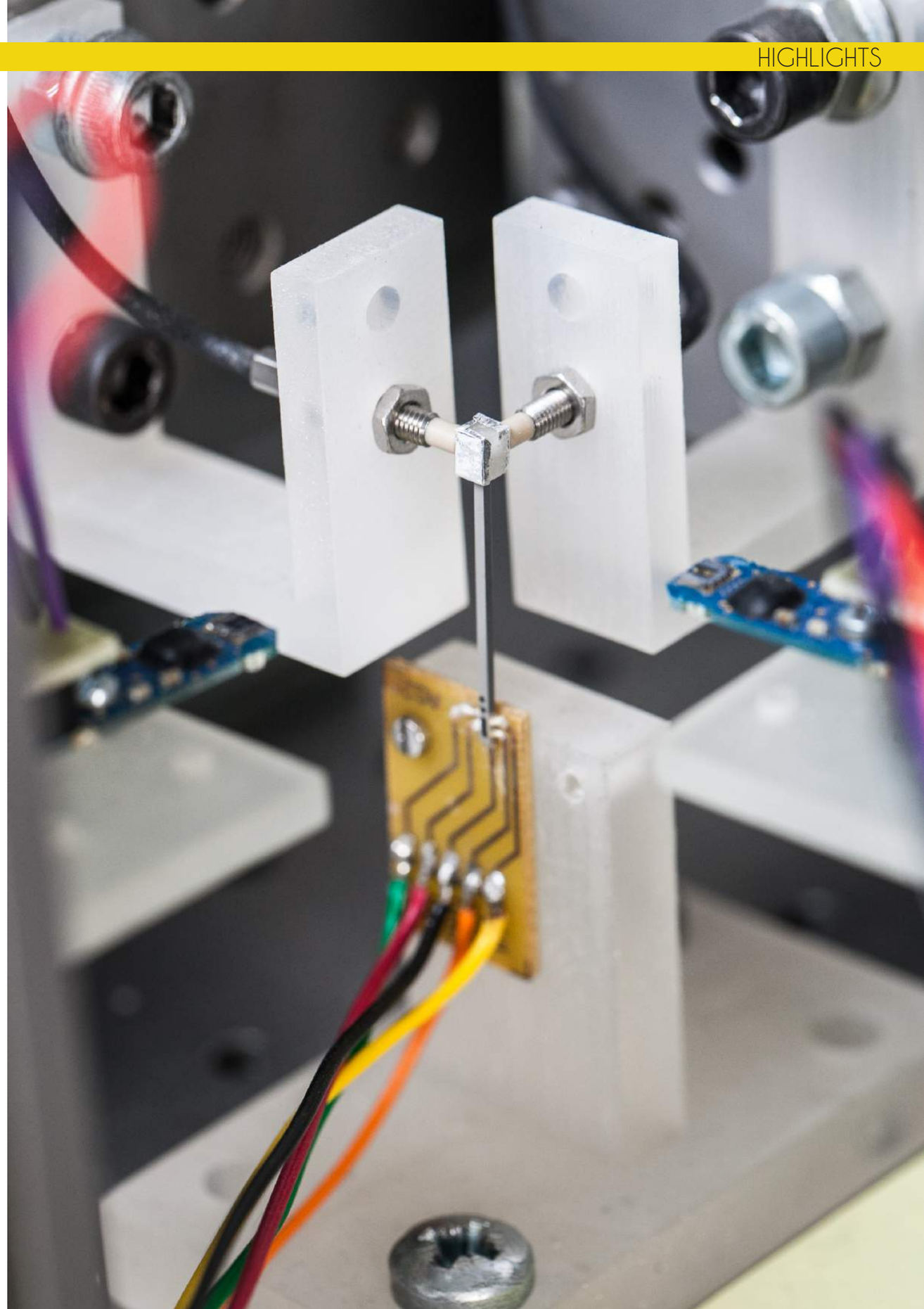
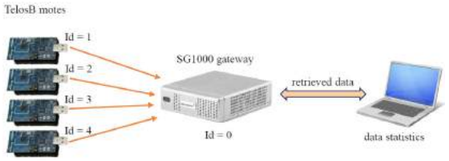
Contact
Morvan Ouisse - morvan.ouisse@femto-st.fr



ENERGY EFFICIENT DATA HANDLING FOR SURVEILLANCE APPLICATIONS BASED ON WIRELESS SENSOR NETWORKS

Wireless sensor networks can greatly enhance environment monitoring and provide techniques for collecting and analyzing data related to some historically unstudied phenomenon. These networks are used in many applications that need continuous monitoring and periodic data collection and analysis. Consequently, a huge amount of collected data is communicated, thus quickly draining the limited sources of energy of sensor nodes. Therefore, it is important to carefully monitor the amount of data to collect and send, while preserving the quality of service expected by the application. One fundamental technique is to allow each node to adapt its sampling rate to the physically changing dynamics, such that over-sampling can be minimized and power efficiency can be further improved. We proposed an efficient adaptive sampling approach based on the dependency of the conditional variance on measurements that fluctuates over time.

This study is based on the one-way ANOVA model and several statistical tests. Additionally, to further reduce the amount of data sent, we proposed a new data aggregation approach aiming to identify near duplicate nodes that generate similar data records. We studied a new prefix frequency filtering approach that avoids computing similarity values for all possible pairs of datasets. To validate our ideas, we conducted hardware-based experiments on 40 Crossbow TelosB node deployed in our lab, with which many data are collected and sent them to a specified SG1000 sink (cf. figure). The obtained results show that our approaches reduce by about 80% of the amount of collected data while still preserving information integrity.



Sample TelosB nodes and the sink used in the experimentation

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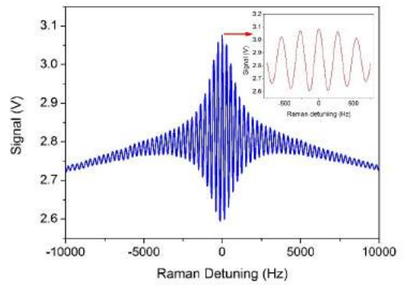
Contact
Abdallah Makhoul - abdallah.makhoul@femto-st.fr

NEW-GENERATION HIGH-PERFORMANCE MICROWAVE CESIUM VAPOR CELL CLOCK

Microwave rubidium vapor-cell atomic clocks are ubiquitous timing devices used in numerous fields of industry including instrumentation, telecommunications or satellite-based navigation systems. Their success is explained by their excellent short-term fractional frequency stability at the level of 10^{-11}, combined with a small size (1 to 10 liters), weight, power consumption (10-30W) and modest cost. Over the last decade, the demonstration of advanced atom interrogation techniques using narrow-linewidth lasers has led to the development of new-generation compact vapor cell clocks.

In this domain, clocks based on coherent population trapping (CPT) have revealed to be promising alternative candidates. A part of the Mclocks European project (http://www.inrim.it/Mclocks/), FEMTO-ST has developed a high-performance CPT-based Cs atomic clock. This clock is based on a diode laser tuned on the Cs D_1 line, an electro-optic modulator for optical sidebands generation and a buffer-gas filled cm-scale Cs cell. This clock combines an optimized CPT pumping scheme and a pulsed interrogation regime to allow the detection of high-contrast and narrow Ramsey-CPT fringes, shown in figure. This clock has recently succeeded in achieving a fractional frequency stability of $2\ 10^{-13}\ \tau^{-1/2}$ up to τ=100 s integration time, a 100-fold improvement compared to existing commercial vapor cell clocks. Efforts are in progress to improve the long-term frequency stability of the clock, with with aim of achieving a stability in the low 10^{-14} range at 1 day averaging time. These studies, crucial to push this technology to industrial applications, are supported by Labex FIRST-TF.



Ramsey-CPT clock signal. The inset shows a zoom on a reduced frequency span of 1.5 kHz. The central fringe linewidth is about 134 Hz (resonance Q-factor ~ 7 10^7).

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Contact
Rodolphe Boudot - rodolphe.boudot@femto-st.fr

MEMBRANE-BASED ELECTRO-OPTIC PHOTONIC COMPONENTS

While photonics is emerging as an attractive alternative to electronics in high bit rate telecommunication systems or sensors, there is a need for specific photonic architectures that cannot be easily produced through clean-room processes. As an example, electro-optical membranes are of great interest in applications requiring low power consumption and small footprint, but their manufacture is currently far from being simple. Indeed, the current prevailing production technique is based on ion slicing, which implies high-end technologies such as ion implantation.
In partnership with the MIMENTO technological center, we propose an easy-to-implement alternative technique by using a circular precision saw. Vertical and horizontal thin membranes have thereby been demonstrated with a record roughness of less than 10nm and aspect ratio of more than 500. Photonic membranes with calibrated thicknesses from 450 nm to 500 µm can be achieved together with integrated tapers guaranteeing low insertion losses. In particular, we propose two patented photonic configurations that allow injecting and guiding light with insertion losses lower than 3dB, and the footprint is 40 times smaller than that of standard components. These developments open the way toward the low-cost miniaturization of photonic components such as lasers, spectrometers, sensors, modulators and associated photonic circuits.
This work has been awarded a special jury prize "Micron d'Or" at the MICONORA 2016 event. It was mainly supported by the Franche-Comté Region, and is going to be pursued toward a SATT Grand Est valorization project.

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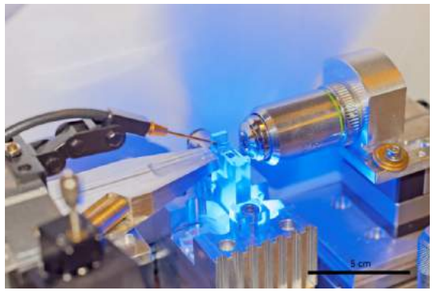
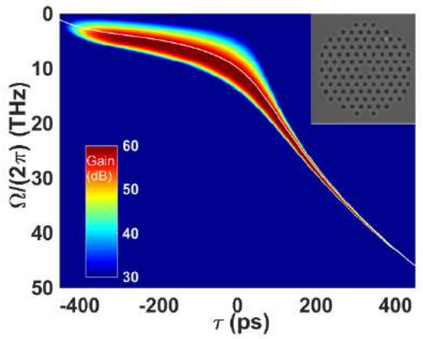


Picture of the characterization setup

Contacts
Nadège Courjal - nadege.courjal@femto-st.fr
Gwenn Ulliac - gwenn.ulliac@femto-st.fr

FIBRE AMPLIFIER FOR ULTRA-SHORT PULSES AT HIGH ENERGY

State of the art bulk laser oscillator exhibits great performances and can deliver ultra-short pulses at high repetition rate. For most experiments requiring non linear interaction between optical pulses and matter, the energy is often increased with subsequent amplifiers. However most of them, although efficient and robust, are based on "traditional" laser amplification and therefore suffer from broadening of the pulse duration together with a restriction of the available spectral region. For example, the tunability is usually confined to a narrow window which limits the range of interesting potential applications sensitive to the wavelength (laser-matter interaction, nonlinear microscopy…). Therefore, designing an experiment entails making a compromise between relevant parameters (energy, wavelength, pulse duration...). The FIBER-AMP project, supported by the Agence Nationale de la Recherche, aims at overcoming these limits by combining new techniques based on compact-robust fibre lasers and ultra-broad band nonlinear optical techniques that circumvent the bandwidth and wavelength limitation of traditional material. The process relies on the nonlinearity of silica, which can provide both large gain bandwidth and high gain values in a compact, rugged geometry. The general idea is to "combine" the useful properties of two distinct laser pulses (one high energy but narrow bandwidth, the other broad spectrum but low energy) and use them to engineer a "perfect" pulse (high energy-broad spectrum). The energy transfer from an intense pulse with narrow bandwidth to a low energy broad bandwidth pulse is achieved in designed photonic crystal fibres.



Simulation of the spectro-temporal gain distribution. This feature should allow the amplification of sub-30 fs pulses at high gain.

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Contact
Damien Bigourd - damien.bigourd@femto-st.fr

DESIGNING A 100% BIO-BASED COMPOSITE SOLUTION FOR TOMORROW HIGH-PERFORMANCE MATERIALS :

A REGIONAL AND EUROPEAN COLLABORATION IN ACTION

In recent years, due to increasing environmental concerns, there has been a growing renewal of interest in fibres and building blocks derived from lignocellulosic feedstock and their composites. These lightweight materials represent attractive materials for engineering applications, in substitution to the traditional synthetic and fossil-based solutions. They are also a great opportunity to design a new family of advanced and multifunctional materials which are renewable.
Within this movement, a close and interdisciplinary collaboration has arisen within the University of Bourgogne Franche-Comté. It brings together three teams from three laboratories of UBFC namely FEMTO-ST-Institute, DRIVE (Département de Recherche en Ingénierie des Véhicules pour l'Environnement, Pr. Stéphane Fontaine) and ICMUB (Institut de Chimie Moléculaire de l'université de Bourgogne, Dr. Laurent Plasseraud). Within the last year, research activities have resulted in the development of a 100% bio-based composite, produced from bio-epoxy and hemp fibres. The thermoset epoxy developed at ICMUB was carried out using a building bio-block catalytically fragmented from a wood constituent and acid anhydride-based hardeners also coming from biomass. The obtained composite has very interesting properties making it a promising material to substitute glass fibre/bisphenol-A based epoxy polymer composites in secondary structural applications in the field of ground transportation. These activities have been mainly supported by Bourgogne and Franche-Comté regions and local authorities.
This activity has also taken this year a European dimension. The core group has expanded and strengthened thanks to the financial support obtained in the framework of the MRSEI (Setting up European or International Scientific Networks) Work Program of the French National Research Agency (ANR). This consortium grouping 17 partners located in 6 European countries has set up a H2020 project, called SSUCHY (Sustainable Structural and mUltifunctional biocomposites from HYbrid natural fibres and bio-based polymers). The SSUCHY project has successfully completed the final phase evaluation of the 2016 call of the JTI BBI (Bio-based Industries), the Public-Private Partnership between EU and the Bio-Based Industries Consortium. This four year project coordinated by Vincent Placet, with an overall budget of 7.41 M€, is focused on the development of multifunctional recyclable bio-based composites with advanced functionalities for applications in transportation and a high value market niches. It is dedicated to the development of concepts, technologies and materials to achieve a complete value chain and prove the principle at the scale of product demonstrators.

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Contact
Vincent Placet - vincent.placet@univ-fcomte.fr

THE DATAZERO PROJECT

Energy efficiency in datacenters has been improving for some years, however the amount of electricity needed for operating and hosting Cloud services is growing with the sizes of the infrastructure and with users' demands. With renewable energies and the usage of direct current in datacenters, we believe that we can cope with this problem. Efforts have been conducted at the computing level in datacenters (service placement and scheduling) and for energy provisioning partly with renewable energies, nevertheless without much interaction between these two efforts. DATAZERO will give consistent solutions for high availability of IT (Information Technologies) services, avoiding unnecessary redundancies, under the constraints of intermittent nature of electrical and service flows (see Figure 1).

The question we address in DATAZERO is:
How to manage the electricity and the service flows in order to deliver services to customers in a robust and efficient manner within datacenters operated with several energy sources?

To answer this question, we identified 7 scientific challenges: (i) make demand and envelope constraints coincide on electrical and IT plans, (ii) properly size the equipment, (iii) optimally command the electrical converters, (iv) schedule and manage the IT load, (v) take into consideration thermal management, (vi) study the complexity of the optimization problem and (vii) develop a simulation toolkit.

The main targets of DATAZERO are middle-size datacenters where IT load can be managed either through Virtualization or Cloud orchestrator (up to 1000 m2 and about 1 MW) as commonly encountered by companies and public institutions

[1] http://www.datazero.org

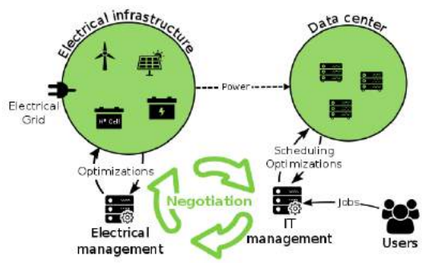

Figure 1: Big picture of the ANR-DATAZERO project

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Contact
Jean-Marc Nicod - jean-marc.nicod@femto-st.fr

NANOBIOANALYTICAL PLATFORM FOR ON-CHIP QUALIFICATION AND QUANTIFICATION OF BLOOD MICROPARTICLES

Cell-derived microparticles are small vesicles (50 - 1000 nm) derived from the plasma membrane of different cells that are present in most body fluids, like blood or urine. They play important roles in various biological processes and are potential biomarkers of various health disorders, hence a growing interest in detecting, quantifying and qualifying them. Unfortunately, their detection is hampered by their small size, their biochemical polydispersity – leading to the appearance of different subtypes of microparticles, – and the abundance of contaminants in biological samples.

In close collaboration with biologists, researchers of the BioMicroDevices group developed a NanoBioAnalytical platform for on-chip investigation of microparticles that combines surface plasmon resonance (SPR) with atomic force microscopy (AFM). Dedicated biochips are developed and produced by FEMTO-Engineering, the technological development Center of FEMTO-ST. The label-free optical SPR sensor allows us for the specific and multiplexed capture and the subsequent quantization of microparticle subsets onto a biochip. Following capture, AFM provides on-chip metrological analysis of the morphology and size of microparticles with nanometer resolution.

The NanoBioAnalytical platform was successfully validated and characterized against two calibration standards, mimicking microparticles and spanning their size range, prior to its application to the study of platelet-derived microparticles. We were able to phenotype, detect, quantify, and determine the size distribution of different sub-populations of microparticles on the whole size-range with high specificity. The platform offers a promising and novel method for clinical and medical studies to characterize microparticles in different biological samples and to understand their implication in various diseases.

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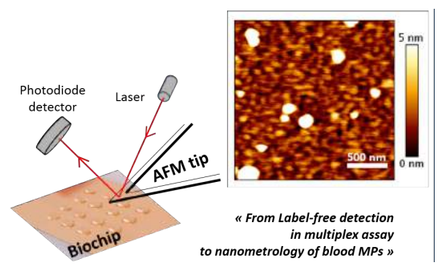
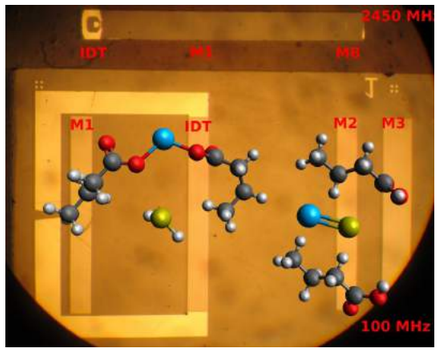


The NanoBioAnalytical platform combines surface plasmon resonance (SPR) and atomic force microscopy (AFM) on a biological chip.

Contacts
Céline Elie-Caille - caille@femto-st.fr
Wilfrid Boireau - wboireau@femto-st.fr

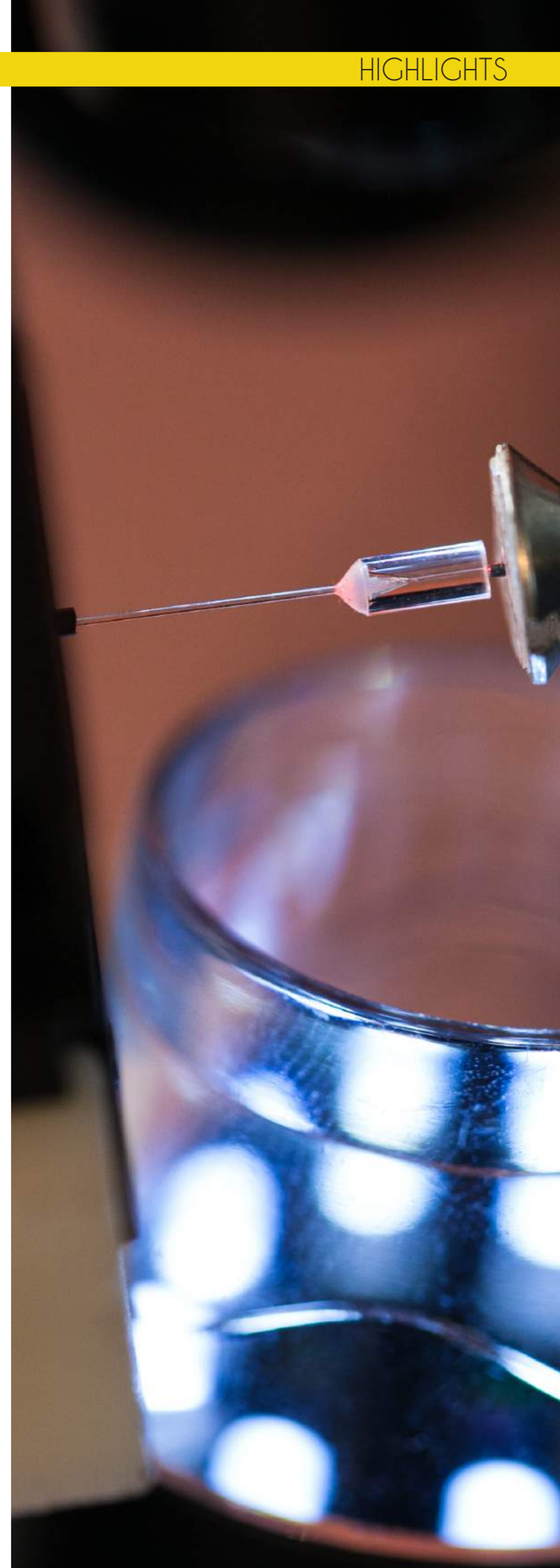
FUNCTIONALIZATION OF ACOUSTIC DELAY LINES FOR SUB-SURFACE PASSIVE WIRELESS GAS SENSING: APPLICATION TO HYDROGEN SULFIDE DETECTION

The detection of chemical compounds in the subsurface is a new pivotal figure in terms of environmental and economic impacts for industrial companies, due to the current standards imposed by governmental agencies. To achieve this ambitious challenge, we propose to design wireless passive chemical sensors, which can be interrogated by Ground Penetrating RADAR (GPR) thanks to the introduction, on the one hand, of a dedicated signature to differentiate the sensor response from clutter, and on the other hand an information (time delay) representative of the compound concentration. In the framework of the joint laboratory PhASES involving the FEMTO-ST institute and the SENSeOR Company, we obtained a grant from the TOTAL Company to develop a wireless sensor, able to detect hydrogen sulphide (H2S) in the ppm range in the ground. We have developed a new resist with two requirements: (1) it can act as an acoustic waveguide to the acoustic wave used to delay and generate the sensor response and (2) its viscoelastic behavior is modified under exposure to H2S. This resist is included in the fabrication of acoustic transducers via processes compatible with the cleanroom facilities of the FEMTO-ST institute. Finally, we have demonstrated that these transducers can be interrogated wirelessly by GPR and that they are sensitive to H2S. CNRS and SENSeOR have patented these results in 2016. In the future, we aim to develop subsurface sensors for the detection of other chemical compounds.



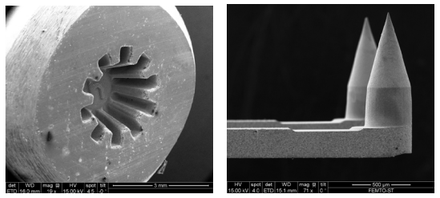
Hydrogen sulfide reacts with the lead ion (blue) in the polymer deposited on the SAW surface to create lead sulfide (right) detected as mass loading or layer stiffening.

Contacts
Jean-Michel Friedt - jmfriedt@femto-st.fr
Frederic Chérioux - frederic.cherioux@femto-st.fr



DEVELOPMENT OF MICRO-MILLING PROCESSES BY µELECTRO-DISCHARGE MACHINING APPLIED TO VERY HARD MATERIALS

Micromanufacturing of highly complex micrometric parts in very hard materials (Carbide, Ceramic) represents a highly challenging issue in modern Mechanical Engineering. Tungsten carbide has very interesting properties in terms of mechanical (high hardness, elastic modulus and density twice as high as steel), thermal (high melting point, a thermal conductivity equivalent to copper brass and a coefficient of thermal expansion three times lower than steel) and tribological (wear) properties. These features are considered in manufacturing processes (machining, blanking, forging; ...) especially for the development of active tools but also in surgery instruments, mining, nuclear, sports or luxury fields. Due to its important hardness (9 on the Mohs scale), this material is obviously difficult to process, especially at microscale. In this context, FEMTO-ST/DMA (µFAB Team) has developed research activities in the field of micromanufacturing processes by Electro-discharge machining. A Sarix SX200 Dual machining equipment (funded by the Bourgogne Franche-Comté Region and the EU FEDER program in the framework of the MIFHySTO platform) allows to realize complex 3D shapes regardless of material hardness. Micro-milling of complex shapes has been developed, as shown in the figures. The figure represents a micro-forging part in a tungsten carbide cylinder (diameter of 4 mm). The resulting part, a micro bevel gear with 10 teeth, 2 mm diameter and a 1.25 mm depth, is obtained after 130 processing hours with a 500 nm depth of cut (all edges have a radius of 60 µm). The figure represents a resonant cantilever for scanning force microscopy applications (Fatah Maloum PhD Thesis – FEMTO-ST DMA/MN2S collaboration). The cantilever is obtained in one tungsten-carbide part with a top radius of 5 µm.

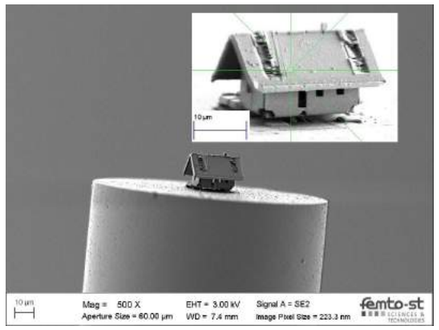


Some applications of µEDM process on tungsten-carbide part :
Left: 3D microshape of a bevel gear,
Right: 3D Cantilever for scanning force microscopy

Contact
Sébastien Thibaud - sebastien.thibaud@ens2m.fr

ORIGAMI MICROSCOPIC HOUSE ASSEMBLED ON TOP OF OPTICAL FIBER

You may never be able to inhabit this microscopic house – and it is much too small for you to see with bare eyes, anyway, – but our µRobotex team was able to assemble it with a resolution of a few tens of nanometers.
The µRobotex station is a powerful micro- and nano-robotic equipment that can cut, etch, pattern, assemble, coat, and fold thin membranes and finally secure complex structures by welding. µRobotex revolves around a dual beam SEM/FIB microscope (Zeiss) placed in a large vacuum chamber together with a 6 degrees-of-freedom robotic arm and a Kleindiek actuator that achieves special assembly processes with 3 'hands'. µRobotex enables true 3D micro- and nano-assembly of chips.
Our engineers built the micro house onto the end of an optical fiber. The house is made from a 1.2µm thick membrane of silica cut in 3 pieces. The base, walls, doors, and windows of the house were patterned into the membrane by focused ion beam (FIB) milling. The 4 walls of the house were then elevated and the base was welded to the fiber. The pre-cut roof parts were folded at an angle of 45°. The fiber was controlled by the robotic arm so that the walls fitted in the patterned roof parts, as mortise and tenon joints. The precision of this operation is down to 50 nm. Finally, a tiny chimney was added on top of the roof - winters can be chilly in these parts.



Credits: the fiber was prepared and operated by Miguel Angel Suarez (Optics department). Jean-Yves Rauch (MN2S & AS2M departments) sputtered the thin membrane and conducted the assembly in the µRobotex station, in collaboration with Olivier Lehmann (AS2M department).

Contact
Jean Yves Rauch - jyves.rauch@femto-st.fr

CODE TEAM

In the last five years, members of the CODE team in the AS2M department have obtained strong results on modeling and control in open multiphysical dynamic systems using the port Hamiltonian approach, which have been applied to realistic problems arising from micro-nano robotics, compliant mechanics, acoustics and irreversible thermodynamics. From a system control theory perspective, they worked on asymptotic and exponential stabilization of boundary controlled port Hamiltonian systems, in both linear and non linear cases, with application to the control of electrostatically actuated flexible nanotweezers for DNA manipulation (see figure). They proposed constructive control design techniques based on energy shaping and succeeded in dealing with the well-known limitation associated to pervasive systems called the dissipation obstacle. The extension of these control design techniques to 2D and 3D systems with application to control in acoustics, fluidic and multidimensional robotics is under study and has led to promising preliminary results. From the modeling and non linear control point of view, they also proposed highly promising extensions of irreversible port Hamiltonian formulations to cope with the modeling and control of irreversible thermodynamic systems (such as reaction systems, active materials etc…). A clever use of the thermodynamic availability function for control purposes was shown to lead to very efficient non linear control design methods through energy shaping and damping assignment.
These activities have been supported by the ANR through two projects, the HAMECMOPSYS project (2012-2016) and the ANR-DFG HINFIDEM project (2016-2020) and by LABEX ACTION.

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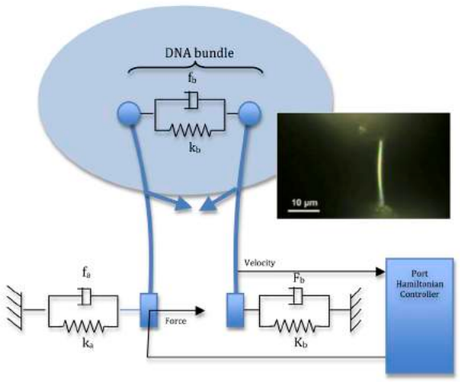


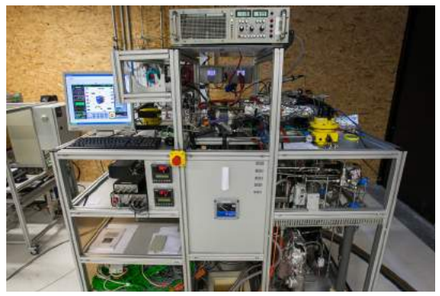
Contact
Yann Le Gorrec - yann.le.gorrec@ens2m.fr

SHARPAC TEAM

The SHARPAC team (Systèmes électriques Hybrides, ActionneuRs électriques, systèmes Piles A Combustible) of the FEMTO-ST Institute is engaged in the design, optimization and implementation of energy management algorithms for hybrid electric systems with or without clean energy sources. This activity is supported by recently obtained funding projects: SUPERNOMA (supported by the DGA / E4V, 2014-2016), DATAZERO (supported by the ANR, 2016-2019) and two projects supported by the Bourgogne Franche-Comté Region.

As part of the SUPERNOMA project for the DGA and in partnership with the SME E4V (www.e4v.eu), the SHARPAC team was in charge of the design, integration and validation of algorithms in order to manage the electrical energy flow between E4V batteries (Lithium LiFePO4) and ultracapacitors for both military and civil applications.

Two test beds have been designed and realized, one with a rated power of 10kW, and a second with a rated power of 135kW. They are based on standard components and an identical control board. The experimental results validate the control designed to be applied to the two test beds of significantly different power range and under large sampling time of measurements with CAN communication. The study also demonstrated that such a power architecture reduces weight and volume for high impulse power applications compared to battery-based only solutions.



Banc d'essais pile à combustible de type Proton Exchange Membrane (PEMFC) pour des puissances inférieures à 1 kW

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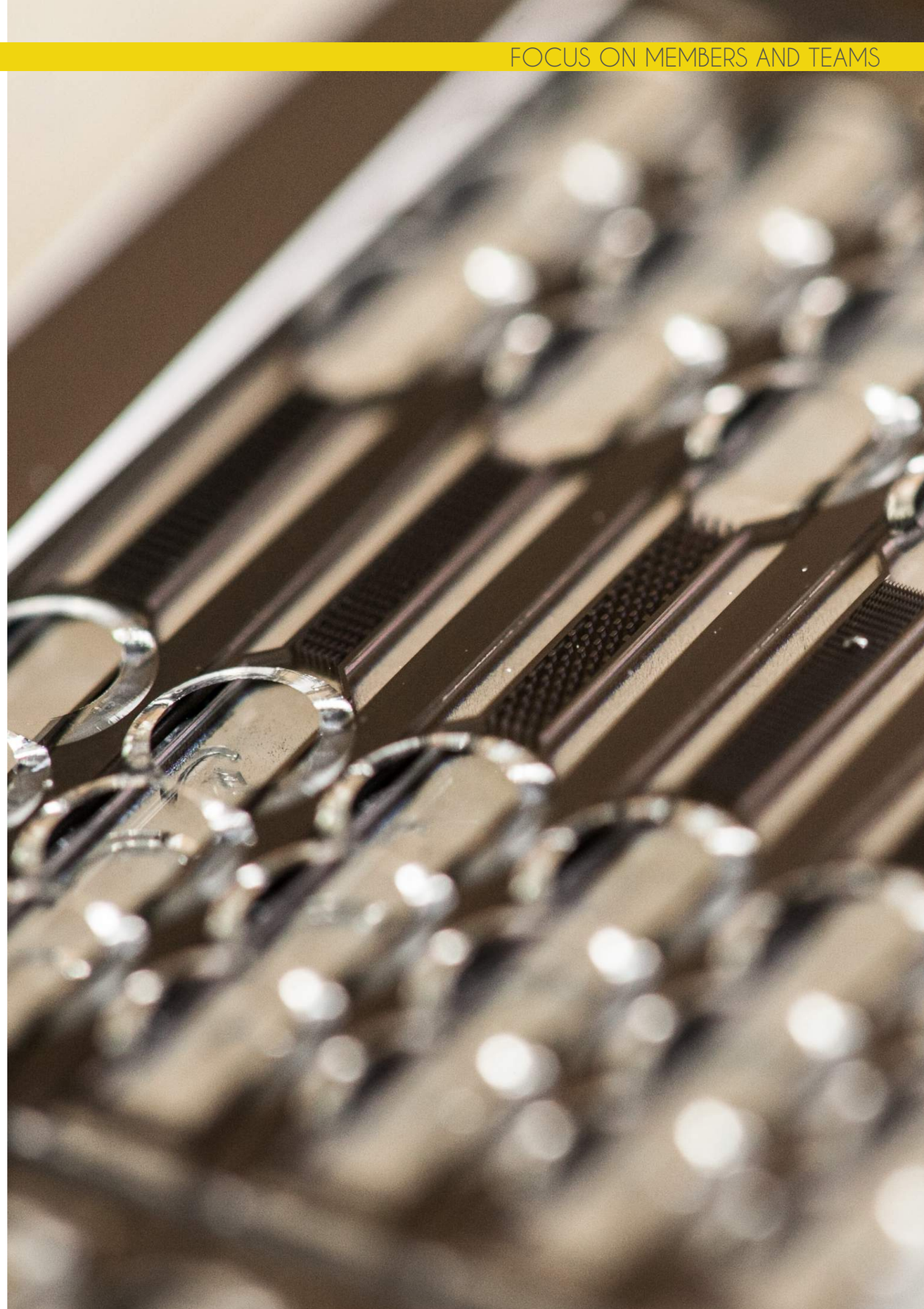
Contact
Mickaël Hilairet - mickael.hilairet@univ-fcomte.fr



NADIA YOUSFI STEINER: CHAIR OF EXCELLENCE AT THE LABEX ACTION

Nadia Yousfi Steiner joined the Labex ACTION in October 2014, as chair of excellence. She teaches at the UFC/ IUT of Belfort Montbéliard and is a member of the FEMTO-ST/Energy department. Nadia worked for 7 years as researcher and project manager at the European Institute for Energy Research in Karlsruhe (EIFER, Germany), in charge of projects linked to fuel cells and hydrogen. She organized the 5th international conference on Fundamentals and development of Fuel Cells (FC) in April 2013 and the 1st international summer school "from diagnostics to Fault Tolerant control (FTC) of Fuel Cells" in July 2016.

Turning fuel cells and hydrogen technology into viable alternatives to conventional systems for sustainable energy production is the leading drive of Nadia's research, which addresses this main question: how could we increase the reliability, lifetime and safety of the complex fuel cell systems while decreasing their cost? Addressing this main question turns out to be crucial to reassure both customers and markets, without whom no wide deployment of these technologies is possible. The idea of a smart self-healing fuel cell is attractive: it consists of an integrated system that is able to detect its own deviations from normal, to analyze these deviations and to take the right decisions to self-heal: (i) change the operating/control conditions so that the incipient fault is deleted or mitigated, (ii) change the control objectives so that the risks are minimized when no faults-counteraction exists, or (iii) call for condition based/proactive maintenance. All the used approaches should naturally take into account realistic constrains: the preferred methods are nonintrusive, cheap, parsimonious towards sensing and easy to integrate online and onboard of an operating system. This matches the typical constrains linked to automotive and stationary (CHP systems) applications.

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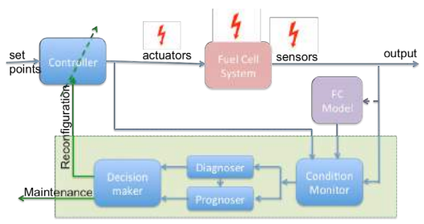


FTC strategy applied to a FC System

Contact
Nadia Yousfi Steiner - nadia.steiner@univ-fcomte.fr

MUAMER KADIC, A MECHANICAL METAMATERIAL GURU JOINS FEMTO-ST

Dr. Muamer Kadic recently joined FEMTO-ST as an associate professor in the field of electrical and electronic engineering. Prior to that, he got a PhD in plasmonics from the University of Aix-Marseilles in 2011. He was a postdoctoral fellow for 5 years at Karlsruhe Institute of Technology, with Prof. Martin Wegener. Muamer is a specialist of metamaterials, a novel class of artificial man-made composites that are engineered to achieve material properties that are hardly found among natural materials. For instance, he demonstrated a class of mechanical materials that behave as quasi-liquids, though they are made from a single solid material and can be 3D-printed (see figure). He also worked on thermal, optical, acoustical and Hall metamaterials. Those achievements and much more can be browsed at his home page.

http://members.femto-st.fr/muamer-kadic/

Muamer, where do you come from?

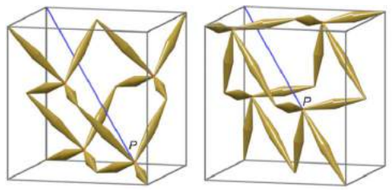
I was born in former Yugoslavia and more precisely in Serbia, but was raised in Bosnia, so that I became a nowhere-boy when Yugoslavia collapsed. In 1993, I arrived in France knowing nothing of French. In 1994, the city council of Vierzon, the small city where my family was accommodated, decided to drop me out of classical studies for a quick formation as bricklayer. I and my scientific future were fortunately 'saved' by my primary school instructor.

Why did you choose Germany for your post-doctoral position?

I chose Martin Wegener because he is a world-class scientist and also – of course – because he accepted me. I believe German people have more collective conscience compared to French people in everyday life, making the organization of research extremely easy and self holding. On the other hand, they seriously lack senior or advanced researchers as permanent staff in universities. They are more nit-picky when it comes to details and they always try to do the best they can at all levels of society, but they can be very direct and rough in the way they express their ideas.

Thanks for joining us in Besançon by the way!

You're welcome! I like the small-scale city with sceneries similar to those of my childhood. I also found an open-minded institute ready to host my future plans. I am presently busy trying to secure funding for my research on mechanical materials and preparing classes.



Schematic structure of pentamode mechanical metamaterials mimicking the mechanical properties of fluids.

Contact
Muamer Kadic - muamer.kadic@femto-st.fr

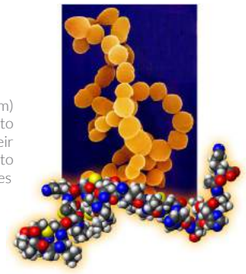
ANNIE FRELET-BARRAND, MEMBRANE PROTEIN SPECIALIST

Annie, a CNRS researcher since 2009, joined the BioMicroDevices group at FEMTO-ST/MN2S in 2015. She was previously with the CEA Saclay near Paris, France. Like a salmon, she had been willing to return back to her native Franche-Comté! Annie was indeed born in the Haut-Doubs region, in the middle of the fir trees. Very early, she chose to devote herself to biology and she became a student at the university of Besançon. She then moved to Switzerland, first in Neuchâtel and then in Zürich where she obtained her PhD in 2006 for her work on functional characterization of plant membrane proteins within plant models.

In 2006, Annie moved with her family to Grenoble for a 3-year post-doctoral position in the CEA/BIG/PCV laboratory, to develop a new system for membrane protein expression in a bacterial expression system: the lactic acid bacteria, Lactococcus lactis. These bacteria are mostly used in agro-food for the production of fermented food such as cheese and yoghurt. Annie continued performing structure-function studies of eukaryotic membrane proteins expressed in L. lactis and her expertise is now shared worldwide with only a few laboratories.

In Besançon, within the highly biophysical environment and the local expertise of nanotechnologies dedicated to surface and interface adapted to studies of biomolecular interactions, Annie has been developing a new type of bio-interface for membrane protein functional characterization on sensor chips by the label-free and complementary techniques that are surface plasmon resonance (SPR) and atomic force microscopy (AFM). She obtained a Bourgogne Franche-Comté funding for Excellence to start this project in collaboration with the worldwide leader of SPR, GE Healthcare. She is also involved with the inter-regional platform, CLIPP, where she, as a member of the steering committee, leads a research axis focused on membrane protein characterization.

http://teams.femto-st.fr/BioMicroDevices/fr/membrane-protein-characterization-microvesicles



The NICE (nisin induced system) for expression of MP (in green) into Lactococcus lactis (black) and their functional characterization into circularised fused membrane vesicules

Contact
Annie Frelet-Barrand - annie.frelet-barrand@univ-fcomte.fr

FOCUS ON THE SPIN-OFF H2SYS, COMING SOON IN 2017

H2SYS is a registered trademark born during the FCTECH maturation project, developed in Belfort, France. It is led by engineers and researchers from the FCLAB-CNRS 3539 research group, in which FEMTO-ST participates as a full member. At the end of the first semester of 2017, this brand will serve as the name of a future start-up company which will commercialize CO2-free electric power generators supplied by hydrogen.

Launched in 2014, the FCTECH project has been initiated with the support of institutional partners: the University of Franche-Comté, and the Region Bourgogne Franche-Comté.

They contributed together to build the foundations of this challenging project with the financing of a worldwide market study that highlighted the market opportunities and the project's economic value. They also provide financial support for the constitution of a leading team including several newly recruited staff. Thanks to this first technological achievements, a new action was triggered to obtain a continued support from the SATT Grand Est in order to develop the technology at a pre-industrial level with the realization of proof of concepts and prototypes.

Currently, 3 people are working full time (within FEMTO-Engineering) supported by 6 scientists from FCLAB – 4 being members of the FEMTO-ST SHARPAC team. With the administrative and organization support from FEMTO-Engineering, they are designing and building the future products. They also promote the technology showing their first prototype of a 1kW mobile generator (corresponding to an autonomy longer than 24h) powered by hydrogen in several famous industrial exhibition fairs across Europe, such as in the Hannover Fair in Germany, but also in Grenoble, Belfort, Mulhouse and Besançon in France.

http://www.h2sys.fr

A part of H2SYS team during Hanover Fair:
Théophile Habermacher, Sébastien Faivre, Fabien Harel.

Contacts
Daniel Hissel - daniel.hissel@univ-fcomte.fr

METAMATERIAL ENGINEERING: A REVOLUTION IN HEARING COMFORT

There is ample scientific evidence that prolonged exposure to noise is dangerous and can cause detrimental effects to society. Sleep disorders, discomfort, increased cardiovascular risks depreciation of real estate prices, productivity losses, learning disabilities: it is estimated that noise exposure amounts to over 57 billion euros in societal costs on an annual basis in France alone. The solutions currently available are mainly based on the intrinsic properties of some materials, which makes today's sound insulators heavy, cumbersome, and sometimes even harmful for health.

In order to remedy this situation, Abdelkrim Khelif, Aliyasin El Ayouch and Yousef Tedja have developed new insulators based on an innovative solution consisting of acoustic metamaterials. The overall idea is to turn any material into the most efficient sound insulator, simply by structuring it according to particular geometrical shapes. More specifically, acoustic resonators are incorporated inside a homogeneous matrix. The resonators couple with impinging waves and can confine them. Depending on the arrangement of the resonators, sound transmission can be substantially reduced and sound attenuation can be dramatically increased. Moreover, because of the subwavelength character of the resonators, the metamaterial provides an omnidirectional attenuation of sound.

Based on this patent-pending technology, a maturation program supported by the SATT Grand-Est has recently been launched with the objective of creating a start-up by the end of 2017.

Aliyasin El Ayouch and Youssef Tejda

Contacts
Aliyasin El Ayouch - aliyasin.elayouch@femto-st.fr
Youssef Tejda - youssef.tejda@femto-st.fr

A PRESTIGIOUS NEW MEMBERSHIP WITH THE TSN CARNOT INSTITUTE

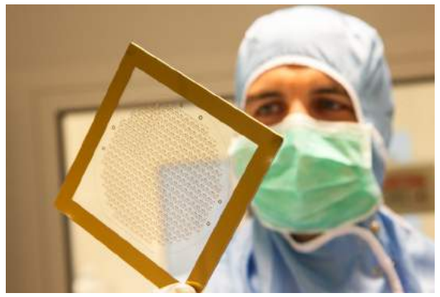
FEMTO-engineering has become member of one of the biggest Carnot institute, TSN (Telecom and Digital Society). FEMTO-engineering is a business unit immersed in the FEMTO-ST institute. It is dedicated to the innovation and transfer of any academic research conducted at FEMTO-ST and being identified as having attractive industrial and market potentials. It thus helps the institute in strengthening its industrial partnerships through R&D, R&T, and technological subcontracting activities.

Several areas are already addressed by FEMTO-engineering, always in strong connection with the research groups thanks to our vision of a necessary deep immersion of transfer activities next to the research groups: Micro-nano technologies, ultra-high stability microwave oscillators, bio-chips, fuel cell technologies, heat energy conversion, fs-laser machining.

Our new membership is an opportunity for FEMTO-engineering to trigger many more industrial interactions and projects, thus facilitating and amplifying the transfer of the many know-how and science innovation stemming from the FEMTO-ST research activities. The Carnot institute TSN is indeed a very important consortium of prestigious engineering and higher education institutions (such as French Telecom engineer institutes, and Polytechnique). The consortium is connected with a broad industrial network, and it is aimed at providing several R&D, R&T services in a spirit of innovation and transfer of academic research results.

In the summer 2016, FEMTO-engineering was successfully validated as a full member of the TSN Carnot institute, due to its already proved dynamism in developing industrial partnerships with high quality management and know-how. FEMTO-ST is very proud of this prestigious membership for its business unit FEMTO-engineering.

http://www.femto-engineering.fr/en



INSTITUT CARNOT Télécom & Société numérique

Contact
sri@femto-st.fr

FEMTO-ST IN FIGURES

The average staff of the institute in 2016 amounts to about 800 people. This comprises the permanent staff (professors, researchers, administrative and technical staff), as well as non-permanent staff (doctoral and post-doctoral students, administrative and technical staff, students, guests, visitors).

The distribution of staff at FEMTO-ST in 2016 was:

- Permanent Research staff: includes assistant, associate, and full professors
- (UFC, ENSMM, UTBM) and full time junior and senior researchers (CNRS)
- Contractual Researchers: PhD students, postdocs, invited professors
- Support for the Research: administrative and technical staff

The (non-consolidated) turnover of FEMTO-ST, excluding permanent staff salaries, consists of the annual allocation of its institutions (University of Franche-Comté, CNRS, ENSMM and UTBM), and its own resources obtained from research contracts with industrial and regional partners, and from national, European funding programs (FEDER, Interreg) and international programs (Ecole Polytechnique Fédérale de Lausanne, Collegium agreement SMYLE).

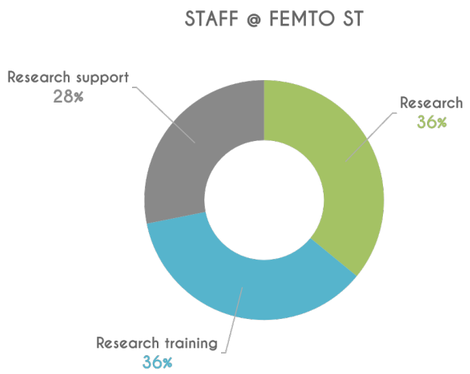
In 2015 the turnover of the institute representing a total budget of € 14,2 million can be broken down as follows:

- Annual funding from institutions (excluding calls for projects and doctoral contracts): 1,5 M€,
- Resources from contracts and research projects: 12,7 M€

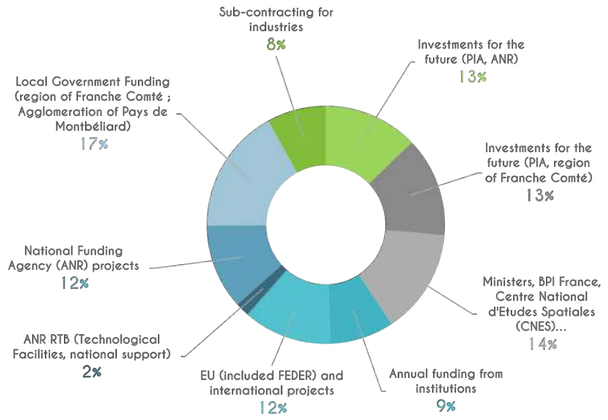
The detailed budget can be drawn up as follows:

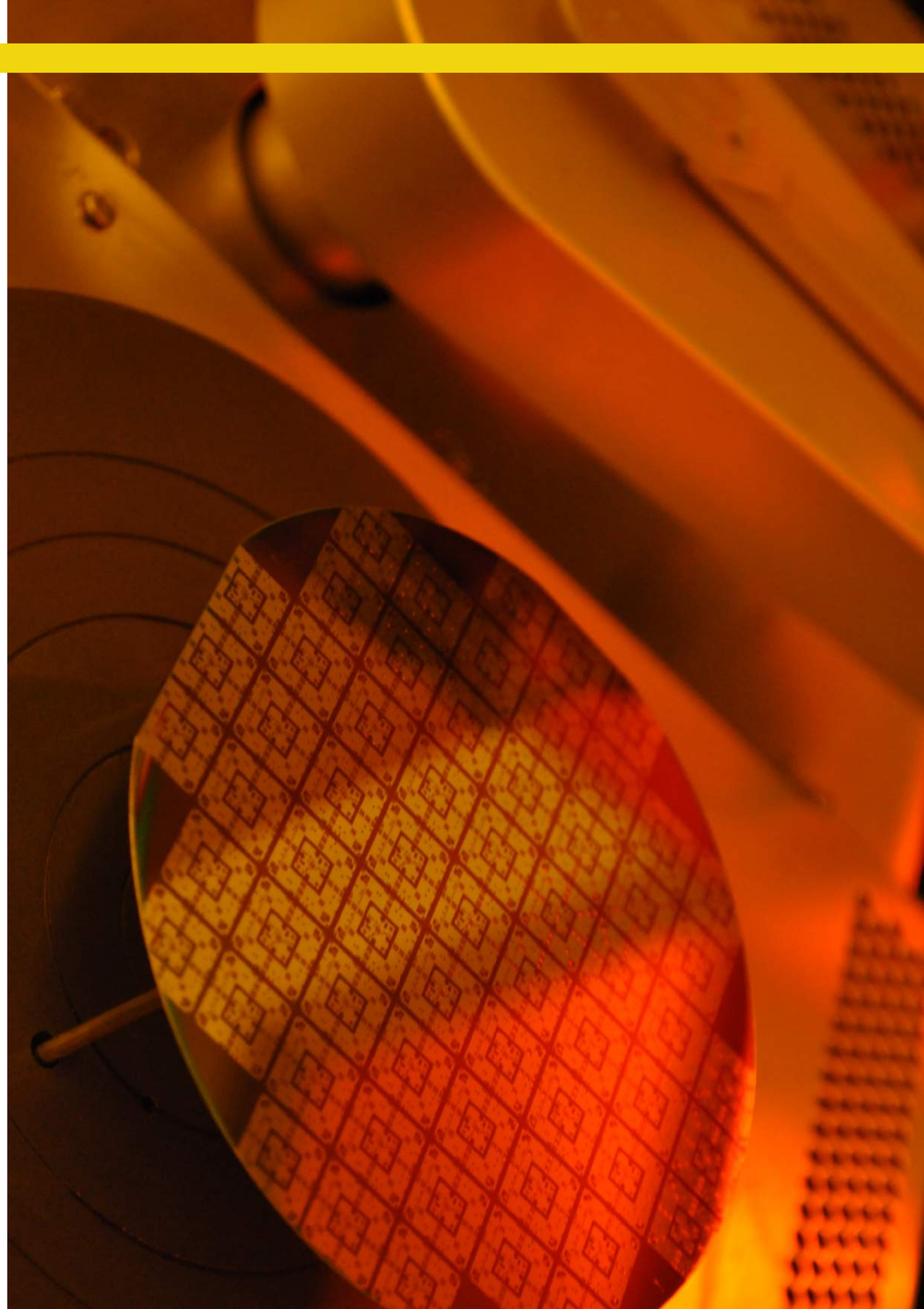
- PhD fellowships (State funding)
- EU and international fundings
- ANR RTB: national funding for technological facilities
- ANR projects: national funding agency (excluding PIAs)
- Local government support, essentially from the Franche-Comté Region
- Direct contracts with private companies
- Institutional fundings (UFC, CNRS, ENSMM, UTBM)
- Other public resources (DGA, CNES, BPI France)
- PIA Region: Regional contribution to the projects of excellence PIA (e.g. Labex, Equipex)
- PIA ANR: national funding agency contribution to the PIA

STAFF @ FEMTO-ST



FEMTO-ST BUDGET IN 2016





With the main financial supports of:

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SCIENCES & TECHNOLOGIES

FEMTO-ST Institute
15B avenue des Montboucons
F - 25030 BESANÇON cedex - France
Tel.: +33 (0)3 63 08 24 00

www.femto-st.fr