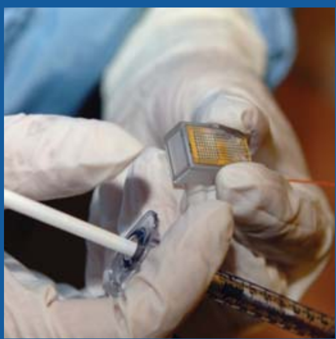
femto-st
SCIENCES & TECHNOLOGIES



2013 Annual Report

FEMTO-ST, a joint Research Institute from :

Content

2013 Annual Report

Editorial

2013 Annual Report

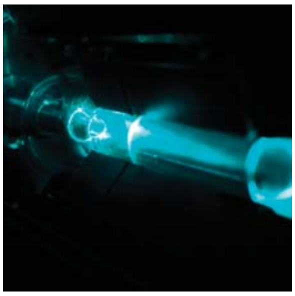
CULTIVATING INNOVATION, FROM BASIC RESEARCH TO INDUSTRIAL PARTNERSHIP AND SPIN-OFFS
DEVELOPING MICRO AND NANO TECHNOLOGIES, INCREASING THE DENSITY OF FUNCTIONS, INTEGRATING INTELLIGENCE, FOR THE ENGINEERING OF COMPONENTS AND SYSTEMS WITH OPTIMIZED PERFORMANCES.

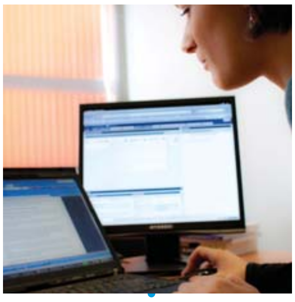
With a staff of almost 700 people, the FEMTO-ST Institute is one of the largest Research Laboratory in France dedicated to Engineering Sciences and Information & Communication Technologies. FEMTO-ST is organized in seven scientific Departments, covering Automatic Control, Acoustics, Computer Science, Energy, Applied Mechanics, Micromechatronics, Microsystems & Nanotechnologies, Optics & Photonics, Time & Frequency. Our Institute was created in 2004 and will then celebrate its 10th anniversary next year.
As expected from its broad area of expertise, FEMTO-ST takes part in many different scientific and technological projects, either leading or collaborating within several national and international projects. Through these collaborations, we develop fruitful partnerships with major Research Centers, but also with SMEs and large companies.
This Annual Report can obviously not consist of an exhaustive report on FEMTO-ST Institute's scientific, technological, transfer activities, awards and publications in 2013. Its objective is to give a brief overview to the reader through a few selected focuses, which emphasize some of the major achievements and highlights of the year. Some of them are aimed to illustrate the multi- and interdisciplinary actions which can be carried out at our institute.
2013 was definitely a very active year for FEMTO-ST. It would not have been possible without the constant involvement, professionalism and creativity of the whole staff of our institute. I wish here to thank all of them.

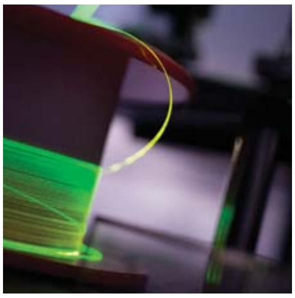
FEMTO-ST Institute is a joint research institute affiliated with the University of Franche-Comté (UFC), the National Center for Scientific Research (CNRS), the National Engineering Institute in Mechanics and Microtechnologies (ENSMM) and the University of Technology Belfort-Montbéliard (UTBM).

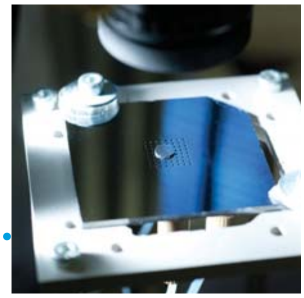
Our efforts to always further improve our scientific excellence, as well as our efficiency in industrial partnerships, could not be possible without the support of this academic environment. Beyond Academia, I am also particularly grateful to the strong support brought by the French State, European Union and the Region of Franche-Comté. Together with these funders and partners, we actively and permanently work towards a broader and better scientific, economic, and societal, influence of FEMTO-ST.
On behalf of the Management Committee of FEMTO-ST, I hope you will enjoy reading this report.

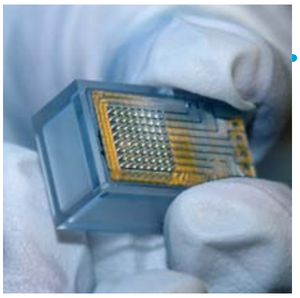
Nicolas Chaillet
Director of FEMTO-ST Institute
nicolas.chaillet@femto-st.fr

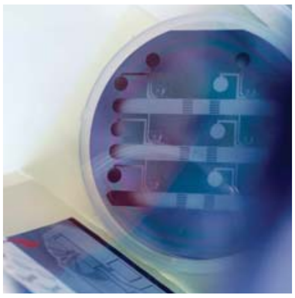


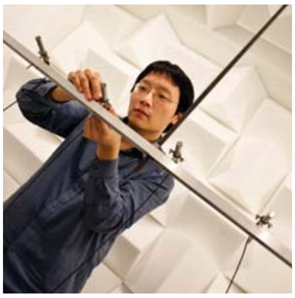


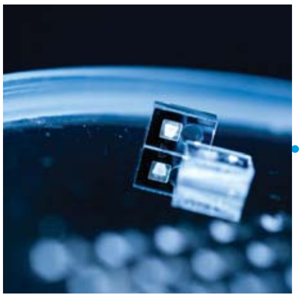












femto-st 2004-2014 10 YEARS
SCIENCES & TECHNOLOGIES

FEMTO-ST in numbers...

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The average staff of the institute in 2013 amounts to about 700 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).

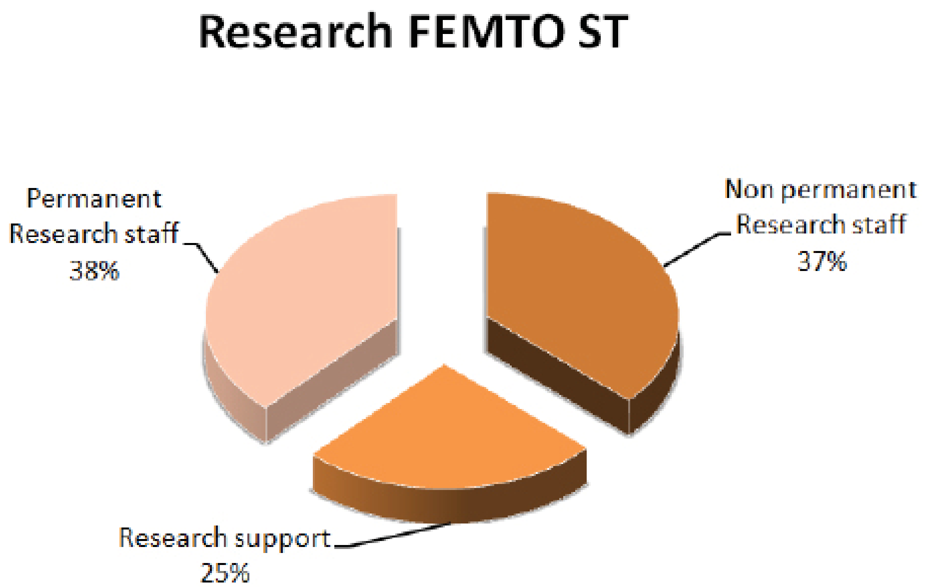
The (non-consolidated) turnover of FEMTO-ST, excluding permanent staff salaries, consists of the annual allocation of its institutions (University of Franche-Comté, CNRS, ENSMM and UTBM), and its own resources obtained from research contracts with industrial and regional partners, and from national and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

In 2013 the turnover of the Institute is:

- Annual funding from institutions (excluding calls for projects and doctoral contracts): 1.2 M€,
- Resources from contracts and research projects: 12 M€,

It represents a total budget of € 13.2 millions. 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 (disclosing PIAs)*
- *Local government support, essentially from the Region of Franche-Comté*
- *Direct contracts with private companies*
- *Institutional fundings (UFC, CNRS, ENSMM, UTBM)*
- *PIA ANR: national funding agency contribution to the PIA*
- *PIA Region: Regional contribution to the projects of excellence PIA (e.g. LabEx, EquipEx)*
- *FUI (Fond Unique Interministérielle)*
- *Other public ressources (DGA, CNES, BPI France)*



Contact
Jean Pascal Carpentier: jp.carpentier@femto-st.fr

Central Support Services and Quality Assurance

2013 Annual Report

ISO 9001 certification for the Administrative, Technical, and Technological facilities at FEMTO-ST

FEMTO-ST is supported by several services to facilitate its various missions as an academic research institute in the field of engineering sciences. In a political ambition to improve its operational efficiency within all these missions, a Quality Certification initiative was launched in 2010, resulting today in an official AFPA ISO 9001 certification for the activities of its operational services supporting the research activities in a broad sense.

The activities concerned by this certification are:
- Management
- Administration (SCA)
- Micro- and Nano-fabrication platform, clean-room facilities (MIMENTO)
- Electronics and Instrumentation, design and prototyping services (SCEI)
- Mechanics, design and prototyping services (SCM)
- Computer and Information Systems services (SCi)
- Industry transfer and partnership (SRI)
- Events, Advertisement, and Communication services (SCC)

The main objective for the Quality Certification is to continuously improve the efficiency and the service quality provided by each of these essential support activities for the FEMTO-ST institute within its numerous missions, among which are top technical research results, efficient administrative and management environment, social and economical impact through interaction with industrial partners, and improved local national and international notoriety.

Together with the general administrative and technical support for all scientific departments in FEMTO-ST, specific technical support related to Mechanical Engineering expertise available for internal research and industrial service contracts is also certified by the Quality Assurance label ISO 9001. The expertise areas of concern cover Materials &Structures, Microanalysis, Forming Processes, Vibrations & Acoustics, Scientific Computing as well as Engineering & Support Team.

A few flagship projects

2013 Annual Report

PIA

Laboratory of Excellence (LabEx) ACTION

Towards smart matters and highly integrated smart structures

The Labex ACTION (ANR-11-LABX-0001-01) is a 8 years triptych led by 3 research partners and addressing:

- A high quality research project dedicated to the integration of smart capabilities (perception, processing, decision, predictive or adaptive action) at the heart of physical structures (cars, medical microdevices, manufacturing equipments, communication networks, etc.) in order to provide them with more sophisticated and cost-effective features;
- A higher education project (creation of several Masters of Engineering linked to "Smart systems & structures"),
- Technology transfer and industrialization of the scientific results.

www.labex-action.fr/en

ACTION key figures:
- Creation in 2012
- 3 research labs: FEMTO-ST, ICB[1] Dijon, LNIO[2] Troyes
- 5 technological facilities: MIMENTO Besançon, Quartz-Tech Besançon, ARCEN[3] Dijon, NANO'MAT Troyes, PICASSO[4] Dijon
- 5 associated labs: EPFL Lausanne, IRTES[5] Montbéliard, Institut de Mathématiques de Bourgogne Dijon, Laboratoire de Mathématique de Besançon, LM2S[6] Troyes,
- Budget: 48 M€ over 8 years

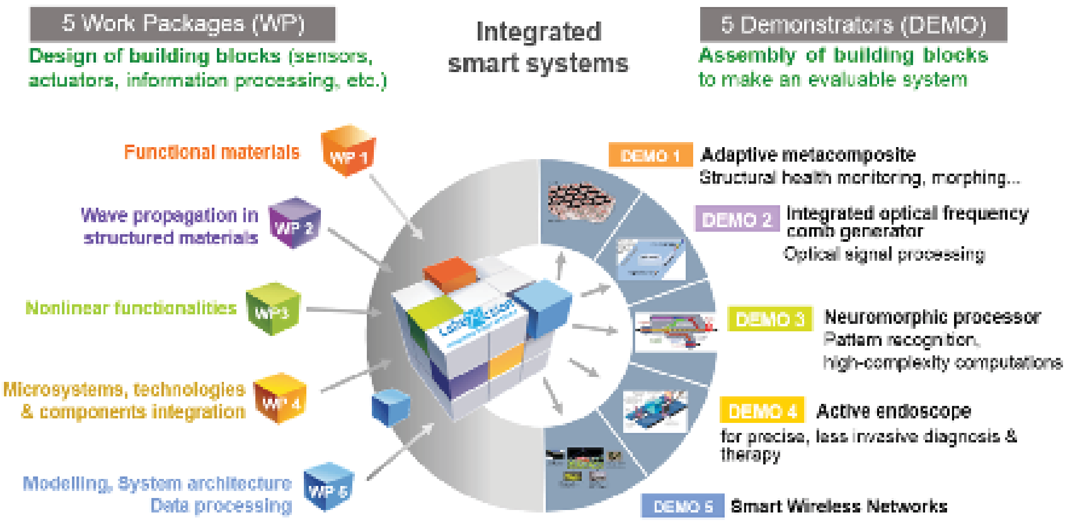
[1] Laboratoire Interdisciplinaire Carnot de Bourgogne
[2] Laboratoire de Nanotechnologie et d'Instrumentation Optique
[3] Applications, Recherches et Caractérisation à l'Echelle Nanométrique
[4] Plateforme d'Innovation et de Conception pour l'Analyse et la Simulation de Systèmes Optiques
[5] Institut de Recherche sur les Transports, l'Energie et la Société
[6] Laboratoire de Modélisation et Sûreté des Systèmes

Adaptive metacomposites for active shape control

The LabEx ACTION aims to become a pole of excellence in the field of the design, study and demonstration of structures or systems ensuring integrated and/or distributed smart functions of:

- Structural Health Monitoring,
- Prognostic Health Management,
- Active control of shape / airflow / noise / vibrations,
- Self-reconfigurability (for a better energy management),
- High complexity calculations,
- High-speed data processing and decision-making.

Scientific programme of the LabEx ACTION:



Target markets: transport, health, energy, civil engineering, telecoms, defense, environment, industrial processes...

Contact

Michel de Labachelerie: labachel@femto-st.fr

FIRST-TF Laboratory of Excellence (LabEx) Facilities for Innovation, Research, Services and Training in Time and Frequency

FIRST-TF key figures:

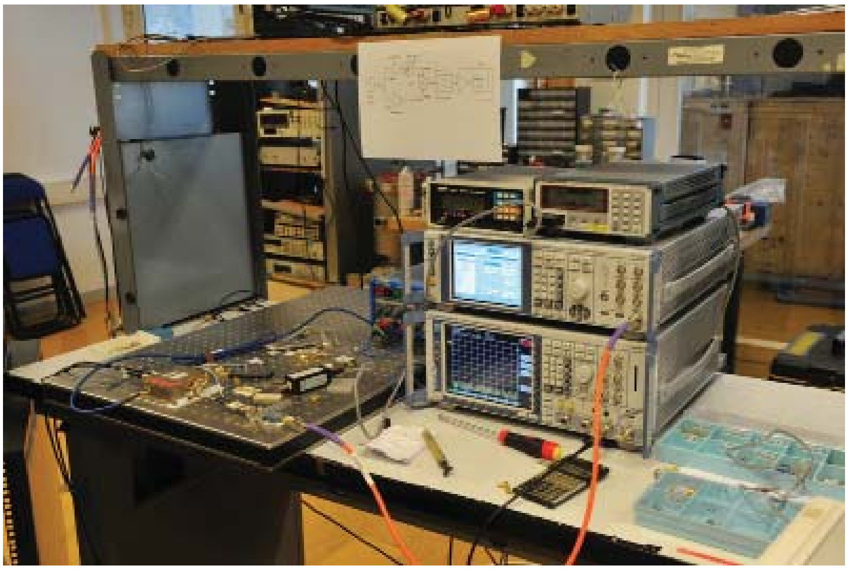
- Creation in 2011
- 5 research labs (core partners): LNE-SYRTE (Paris); FEMTO-ST, GéoAzur (Nice); LPL (Villetaneuse); UTINAM
- 15 associated labs and 15 agency or industry
- Budget: 6.5 M€ over 8 years

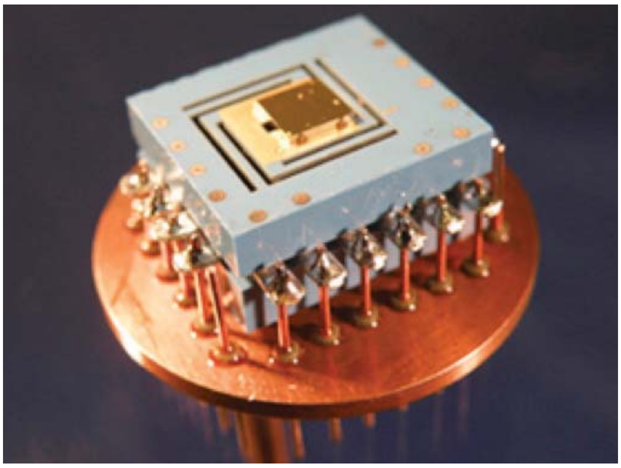
The first goal of FIRST-TF network is to show visibly the French coordination of the T/F research community, and to ensure the best overlaps and complementarities between the existing coordinations.
The second objective of FIRST-TF is to improve the capacity of T/F teams to propose collaborative research projects in the frame of large existing projects (for instance ACES/PHARAO, metrological fibre network utilization, ...) or for starting new projects, with high risks but also high potentiality.
The third objective of FIRST-TF aims at increasing the interactions between laboratories and industry, with the will to improve the transfer of technology and know-how.
The fourth objective of FIRST-TF is to build innovative education and training offers on T/F metrology, with envisaged thematic extensions to high precision measurements and their applications.
The last but not the least goal of FIRST-TF concerns outreach, and especially the popularizing operations towards schools and general public. Various aspects shall be explored: website dedicated to the popularization of T/F, public conferences, mobile exhibitions for schools, etc...

Contact

Enrico Rubiola: rubiola@femto-st.fr

FIRST TF





Oscillator IMP, Equipment of Excellence (EquipEx) Oscillator Instability Measurement Platform

Time, and equivalently frequency, is the most precisely measured physical quantity. Nonetheless, the demand for higher precision keeps growing, from fundamental science to everyday applications.

As a matter of fact, precision and accuracy depend on the amount of time measured, exactly as a molecule, an airplane or a planet cannot be "weighed" as precisely as a one-kilogram mass.

Scanning the technology, we notice that virtually all devices and systems rely on an oscillator stable for a suitably short measurement time τ. By contrast, the accuracy at long τ is provided by an external reference, and ultimately on primary atomic clocks. This pattern is found in radars, telecom, computer boards, particle accelerators, geodesy, space missions, GPS and navigation, photonic systems, internet timing, to mention a few. In these domains, frequency fluctuations and noise are more relevant than accuracy. The scope of "short τ" spans from µs to days, depending on the application.

Surprisingly, National Laboratories focus on absolute accuracy and on atomic clocks, and pay comparatively little attention to the world of "short τ" – oscillators, fluctuations and noise.

Even more surprisingly, one would recall the fact that the Galileo-Huygens pendulum enabled the precise measurement of short intervals (1 s to 1 d) and opened the way to zillions of applications. By contrast, a small group of astronomers succeeded in adjusting the pendulums to the rotation of the Earth around the Sun.

The Oscillator-IMP project aims to be the world-leader facility dedicated to the measurement of noise and short-term stability of oscillators and related devices, including microwave photonics, widely available to Agencies, to research institutions and to private companies, in the spirit of global competition and economy.

However ambitious, this project benefits from the high profile of our Time and Frequency Department. Through the LNE-LTFB, we are already affiliated to the LNE and we already have the highest-level COFRAC accreditation for phase noise and frequency fluctuations. Still through the LNE-LTFB, we are one of the 8 laboratories listed by the BIPM for the measurement of frequency fluctuations. And the one and only laboratory listed by the BIPM for phase noise measurements.

Contact

Enrico Rubiola: rubiola@femto-st.fr

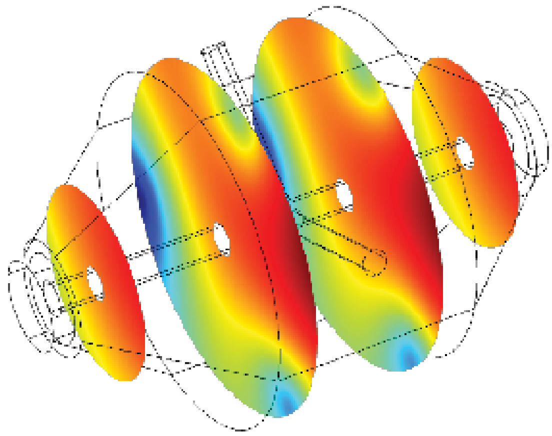
A cornucopia of projects in progress or about to start:

A part of the PIA, or closely related to:
- Liquid-He etalon, target 3×10^{-17} laser stability
- Spherical etalon, target 8×10^{-16} laser stability
- Small etalon, 1", target 2×10^{-15} laser stability
- Two femtosecond lasers, accurate link between optical and µwave frequency
- Three liquid-He µwave sapphire oscillators, 3×10^{-16} stability
- Low-power liquid-He µwave sapphire oscillator
- Three H masers, contributing to int'l time TA
- Shielded chamber for EMC tests and pollution-free µwave/RF noise measurements
- Two-way microwave station for worldwide clock comparison at 100 ps accuracy
- Carrier-phase GPS for worldwide high-accuracy clock comparison
- CERN White Rabbit time/frequency distribution over optical-fiber Ethernet, 1 ns accuracy
- Innovative digital instruments for the measurement of frequency stability and noise
- Tree-cornered-hat statistics
- Stability measurement of MEMS resonators

Oscillator IMP key figures

- 100% Besancon (5/6 FEMTO-ST, 1/6 Utinam)
- ANR 4.2 M€ (3.5 M€ phase 1, over 3.5 years)
- Region : 1.5 M€ in 2012-2013.
- 250 m² building space at ENSMM.
- One ENSMM engineer (permanent, scheduled); Implementation will take 6 full-time engineers over 3 years, and the contribution of 20 researchers. Gradually operational starting late 2014
- Five work packages: Microwave photonics, Microwaves and RF, General metrology, Time scale, Digital electronics.
- Kickoff May 31, 2013, at ENSMM, Besancon

Web site http://oscillator-imp.com (under construction, and hosted by FEMTO-ST)



Mechanical cryogenic silicon cavity simulation

µROBOTEX Equipment of Excellence (EquipEx)

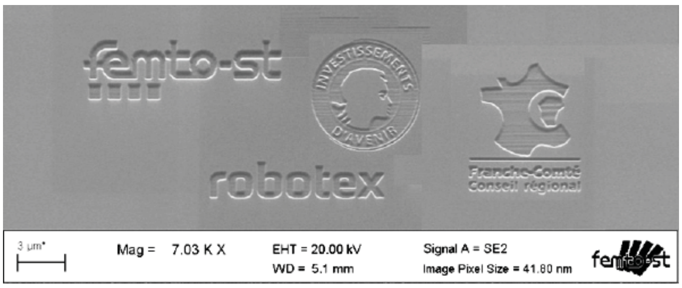
Exploring the nanoworld and building nanorobots able to interact with nano-objects are major challenges of today's research and require high performance equipment.
The µROBOTEX platform is a facility dedicated to the development of micro/nanorobotics and micro-assembly projects on objects whose dimensions are below 10µm. Access to the facility is open to academic and industrial partners for their research and/or development projects. µROBOTEX was funded by the EQUIPEX ROBOTEX (N° ANR-10-EQPX-44-01) of the PIA (Programme d'Investissements d'Avenir) and the Region of Franche-Comté. Equipment: 760,000 € (excl. tax), operation: 97,000 € (excl. tax) and Staff: 105,000 € (excl. tax).
µROBOTEX consists of a SEM (Scanning Electron Microscope), a FIB (Focusing Ion Beam) and a GIS (Gas Injection System). The SEM has a wide chamber (500mm diameter x 300mm height) able to host a 6 DoF microrobot, a laser interferometer and various tools for handling and characterization of micro/nano-samples. Located at ENSMM, in the AS2M department of FEMTO-ST institute, µROBOTEX has been operational since early 2014 and first SEM imaging and FIB experiments have been successfully performed.

The aim of µROBOTEX is to provide researchers in micro/nanotechnologies with competitive instruments at the international level. Combining knowledge on microsystems, physical and chemical phenomena at nanoscale and control theory, this facility represents a unique environment for automated micro/nano-assembly and position/force feedback manipulation and characterization of samples. A main goal of µROBOTEX is to improve robustness at nanoscale through joint use of SEM-based visual servoing and control feedback with embedded force/position sensors.

Web: http://equipex-robotex.fr/thematiques/micro-nano-robotique-microrob/
E-mail: microrobotex@femto-st.fr

Contact
Yassine Haddab: yassine.haddab@femto-st.fr

µROBOTEX facility.



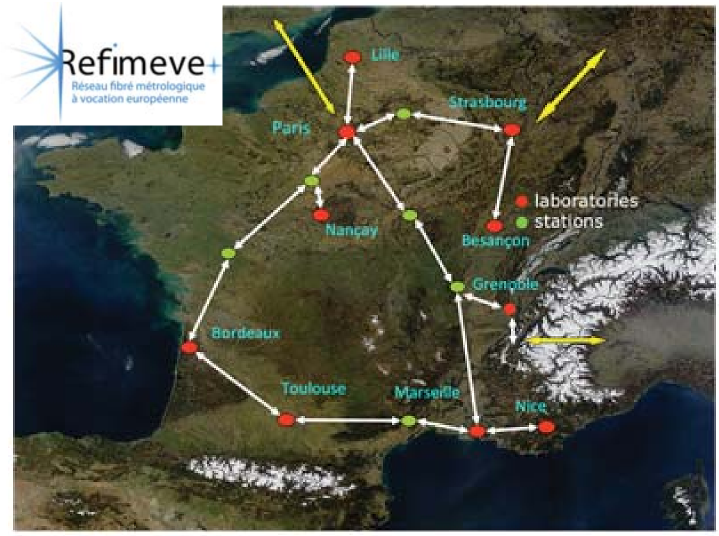
Etching on silicon.

REFIMEVE+ Equipment of Excellence (EquipEx)
Metrological Fiber Network with European Vocation +

Metrological Fiber Network with European Vocation, and National infrastructure for the dissemination of highly accurate and ultra-stable optical wavelength via optical fibers

REFIMEVE+ key figures:

- Created in 2012
- Partners in France: 18 Public labs, CNES, RENATER (NREN), IDIL (private company), Extensions under study, Link to other European Countries, Transfer of absolute time
- Budget: 6.7 M€ over 8 years



Extensions under study
Link to other European Countries
Transfer of absolute time

REFIMEVE+ (REseau FIbré MEtrologique à Vocation Européenne+) is based on the technology developed by LPL and SYRTE for the ultra-stable frequency transfer over long-haul fibers on a public network. It was experimentally demonstrated on a span from Villetaneuse (close to Paris) to Reims that the clock signal can be transmitted, throughout the Internet academic network RENATER over 540km, with an "reproducing" accuracy of $2x10^{-19}$ after one day measurement time. This performance relies on the precision measurement of the round-trip time, which enables the compensation of the delay introduced by the fiber, and of courser of its fluctuations.
This result paves the way to clocks comparison at a continental scale using clocks whose accuracy is of parts in 10^{-16}, and targets the 10^{-17} in a near future. REFIMEV+ has the potential to replace the GPS as the standard method for clock comparison, pushing precision and accuracy to the level required by modern optical clocks.

The project aims at broadcasting the standard optical frequency to 21 French labs, and gradually extend to other European Countries. The broadcasting of absolute time is also under study.

While the highest-level of precise and accurate frequency comes from SYRTE, FEMTO-ST will have the second largest set of oscillators and atomic frequency standard at French scale. This is due to the Oscillator IMP Equipex, and also to the collaboration with UTINAM (the physics institute in Univ. of Franche-Comté), in turn a partner of Oscillator IMP as well. The large set of oscillators and standards makes FEMTO-ST a privileged collaborator of SYRTE and LPL for testing the system, and also for physical experiments that require accurate and stable frequency at two ends of the fiber. While Oscillator IMP is specialized in the measurement of small fluctuations and noise, REFIMEVE+ is aimed to provide the highest absolute accuracy.

Contact

Enrico Rubiola: rubiola@femto-st.fr

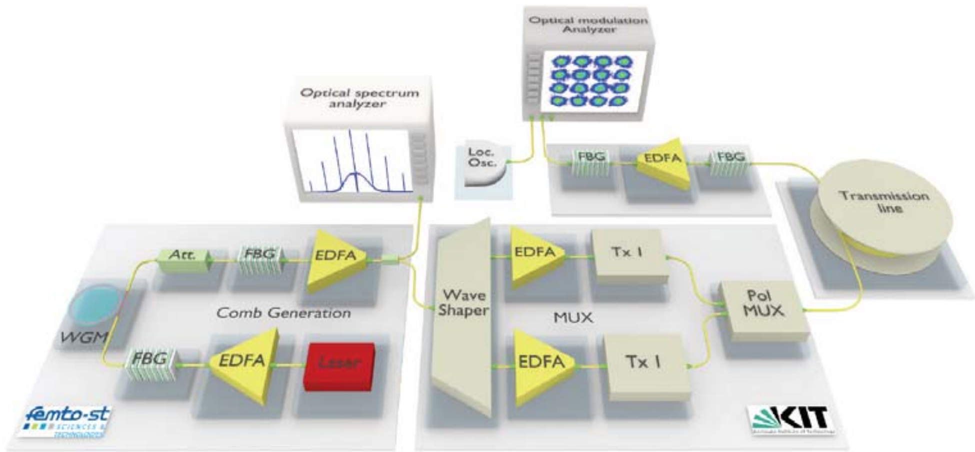
ERC

European Research Council
Established by the European Commission

Ultra-high capacity optical telecommunications

(in collaboration with the Karlsruhe Institute of Technology - KIT)

Yanne CHEMBO
ERC NextPhase and LabEx ACTION



Simplified schematical representation of the experimental system used for the data transmission. This project results from the collaboration of two ERC projects (Next-Phase/Chembo for FEMTO-ST; EnTeraPIC/Koos for KIT).

Optical frequency combs are characterized by their exceptional spectral purity and coherence. They are therefore ideal candidates to be coherent multi-wavelength emitters for ultra-high capacity optical fiber telecommunication networks. These networks are in constant need for ever more transmission bandwidth, because the internet traffic steadily increases at the vertiginous rate of 60% per year, and has been multiplied by 100 in the last 10 years.

In collaboration with Christian Koos's group at the Karlsruhe Institute of Technology (KIT, Germany), we have performed a proof of concept experiment which has enabled us to transmit data with advanced modulation formats at 400 Gbit/s over a few meters, and 200 Gbit/s over 80 km.

In order to give an order of magnitude evidencing how important this transmission capacity is, a 200 Gbit/s corresponds to more than 3 million simultaneous phone conversations. Such a link could enable the transmission of all the phone conversations occurring at each moment in Europe.

The most advanced coherent telecommunication architectures, which are currently under deployment, have a maximal capacity of 100 Gbit/s per channel. Our system allows transmitting up to 130 Gbit/s per channel: in other words, it is already more efficient than the systems that are currently installed by the telecommunication operators.

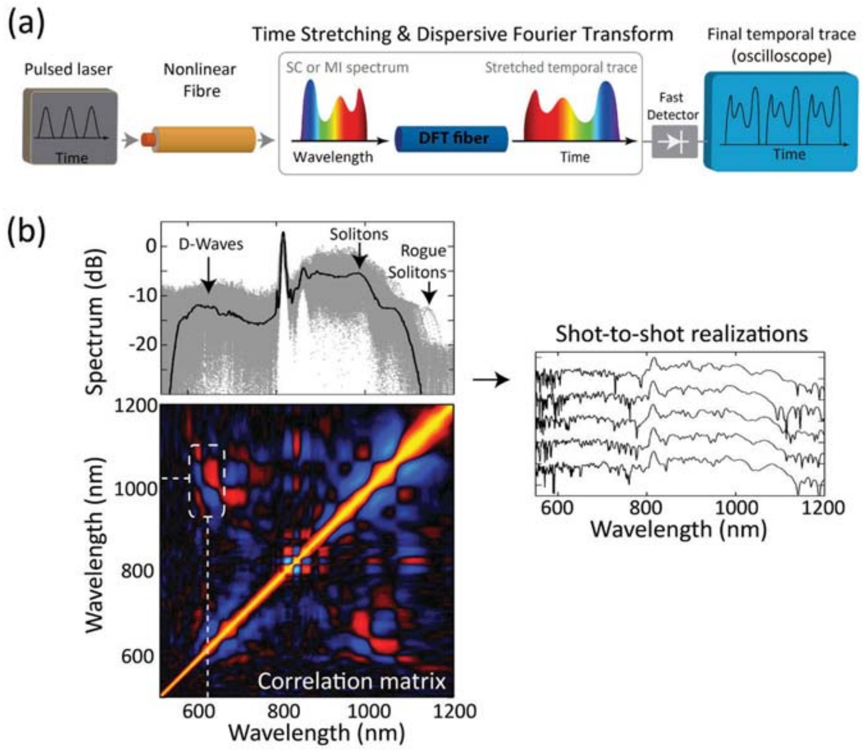
Contact

Yanne Chembo: yanne.chembo@femto-st.fr

Extreme events in Photonics

(in collaboration with the University College Dublin)

John DUDLEY
ERC MULTIWAVE (2011-2016), ANR Optiroc and LabEx ACTION



(a) Experimental setup for real-time measurements using the dispersive Fourier transform technique (DFT).
(b) Characterization of strong shot-to-shot fluctuations in octave-spanning SC generation. The arrows show the dispersive waves and solitons but also the presence of rare "rogue" events. The correlation matrix highlights the complex coupling mechanisms between wavelengths in the spectrum, particularly between solitons and dispersive waves (boxed area).

Recent work in nonlinear fiber optics has demonstrated qualitative and quantitative links between instabilities in optical propagation and the giant destructive rogue or freak waves on the surface of the ocean. The analogy between the appearance of instabilities in optics and the rogue waves on the ocean's surface is both intriguing and attractive, as it opens up possibilities to explore the extreme value dynamics in a convenient benchtop optical environment. It also has direct practical links in understanding instability processes in optics and photonic systems.

Our research has carried out a number of controlled experiments in optics to study the emergence of strongly localized structures from both noise, and controlled initial conditions. We have developed generalized theoretical and numerical models for various classes of nonlinear extreme wave solution, and developed a novel real-time technique to record optical spectra on a shot-to-shot basis with a view to record ultrafast correlations.

Experiments have especially focused on real time measurements of rogue waves in octave-spanning supercontinuum generation and the control of modulation instability through external seeding.

Contact

John Michael Dudley: john.dudley@univ-fcomte.fr

TEMIS Sciences

A new building and extended clean room facilities for the institute, before the end of 2014

The Region of Franche-Comté is strongly willing to consolidate its position as a major European contender in the innovative sectors of micro and nanotechnology.

In this context, the ambitious project "Temis Sciences" aims to gather within the TEMIS Technological Park, most of the Besançon–based human and technological resources of the FEMTO-ST Institute. It will thus provide a high-performance scientific environment to its research teams and to the nearby companies.

This real estate project includes two complementary actions whose construction began in March 2012 :

- **a 850 m² clean room extension**, already inaugurated in November 2013. It allowed to double the surface of clean room facilities dedicated to micro- and nano-fabrication, also bringing together, close to its main users, all the related technological facilities into a single place. With this extension, the MIMENTO technology platform now spans almost 1400 m² (including 865 m² premises ISO class 5-7), thus consolidating its position among the six major French technology research platforms.

- **a new research building** (5300 m² of usable floor space over 6 levels) will host from the end of June 2014, 260 members of the institute, from 2 (out of its 7) scientific departments (micro nano sciences & systems and Optics), as well as the FEMTO-ST executive board and technical or administrative services.

A global financial support amouting to 33 822 000 €:

CONSTRUCTION BUDGET: 32 780 000€
European Union (ERDF): 15 600 000€
Region of Franche-Comté: 7 630 000€
French Government: 7 100 000€ (of which 200 000€ from the CNRS)
Doubs General Council: 1 850 000€
Besançon Metropolitain District Council: 600 000€

INITIAL EQUIPEMENT BUDGET: 1 042 000€
funded by the French government

Contact
Francis Miller: francis.miller@femto-st.fr

MIMENTO: A new beginning

In October 2013 we inaugurated a new extension to MIMENTO, the clean-room facility of FEMTO-ST. MIMENTO is member of the French network of technological facilities Renatech and is now spanning 865m^2 of ISO 5, 6 and 7 zone. The reorganized space is split between different areas corresponding to the different family of processes offered in the clean-room: photolithography (ISO 5 and 6), chemistry, thin-film deposition, plasma etching, nanotechnology, packaging (ISO 5) and characterization. Additionally, we provide space for biology and wet experiments, directly connected to the fabrication facilities. The clean-room is staffed by about 9 engineers whose main tasks are the training of users, the development of new processes and the maintenance of equipment and facilities. They also work with research teams from FEMTO-ST and other labs on cutting edge research projects.

A key evolution in this new configuration is that we try to put in place a good environment for transfer between research and industry by making ample space for industry partners next to the space devoted to academic researchers. First, more than 25% of the area is devoted to an industrial line capable of small series production that is operated solely by staff from the startup company frec|n|sys. This constraint is imposed to allow high yield and repeatability as compared to the academic tools with access based on multi-user operation. Additionally, there are 4 labs (about 15m^2 of ISO 7 space) that can be rented out to companies for months or years to facilitate the development of prototypes, perform clean assembly or packaging, etc. Finally, to foster even more this spirit, FEMTO-Engineering, a private foundation for transferring to the industry technologies developed at FEMTO-ST, will have some of its staff housed close to the facilities for stronger interaction with the engineers in charge of the equipment.

Access to these facilities is open to all researchers from academia and industry through the Renatech network. You just need to open a project at https://www.renatech.org/projet/ - and start working !

Contact

Franck Chollet: franck.chollet@femto-st.fr

the TEMIS Science project and the extended building for the clean-room facilities are mainly supported by funds from:

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Grand Besançon

2013 Highlights

Silver medal award

John Dudley, professor at UFC, was awarded the prestigious CNRS Silver Medal, for his pioneering research on supercontinuum generation in fiber optics and the study of its noise properties as a means to understand giant oceanic rogue waves

Optical fibers are a truly disruptive technology. They are central to modern telecommunications as they carry internet, television, telephone and video-conferencing signals, and have important applications in many other areas such as medical imaging, sensors, metrology, and so on...

An optical fiber is a very thin glass strand with internal properties that allow the confinement and guiding of light waves along its length. The fact that light is confined over such a small area greatly increases its intensity and leads to significant new nonlinear effects as the interaction between the material of the fiber and the electric field of the incident light wave is greatly enhanced.
This enhancement has spectacular consequences, and can lead to an initially monochromatic (single color) laser beam being transformed into a "supercontinuum" of light, a white light rainbow of color yet with the brightness of a laser. It was the studies of the physics of this process of supercontinuum generation and its applications in applied and fundamental physics that was the subject of the CNRS Silver Medal award to John Dudley.

Research Impact

The white light of a supercontinuum has found use in an extremely wide range of applications. Optical telecommunications can be improved with greater information transmission capacity, fields such as spectroscopy, imaging and metrology all greatly benefit from the tunability and flexibility of the supercontinuum, and when combined with stabilization, it can be used to measure optical frequencies in a way that can be used to test fundamental theories of physics.

From an even more surprising perspective, the mechanisms responsible for generating the supercontinuum have in fact been shown to be analogous to the mechanisms that lead to the mysterious oceanic "rogue waves" that have such a fearsome reputation for maritime destruction. John Dudley's studies of supercontinuum noise and stability has led to a number of new insights into how these rogue waves are formed, and even shown ways that they may be either generated deliberately or suppressed altogether. These results have led to new collaborations with international teams in both optics and ocean wave physics, illustrating the tremendous added-value of interdisciplinary research, a major objective of FEMTO-ST.

Jean Yves Marzin, Director of the Engineering and systems sciences institute of CNRS awarding the medal to John Dudley

Contact

John Michael Dudley: john.dudley@univ-fcomte.fr

SMART SYSTEMS FOR A BETTER LIFE

SMYLE, an International Swiss-French Collegium

(Smart sYstems for a better LifE)

Codirectors : Christophe Gorecki (FEMTO-ST), Pierre André Farine (EPFL)

On October 10, 2013 was signed the agreement for a French-Swiss Collegium SMYLE. Thanks to scientific and geographical proximity between the FEMTO-ST Institute and the STI (Sciences et Techniques de l'Ingénieur) Faculty at the EPFL, the launching of the "SMYLE" Collegium will create an ideal framework for long-term collaboration combining research education and innovation. The SMYLE Collegium aims at building a strong Joint Knowledge Hub in promising research fields such as :

- In-vivo biomedical imaging with the development of components and MEMS scanners for endomicroscopes, and the implementation of on-chip microscopy demonstrators applied to imaging of biological tissues,
- Multi-scale microrobots for biomedical applications: (i) millimeter-scale microrobots for inspection and manipulations inside the human body, and (ii) micrometer-scale microrobots for ultra fast and ultra selective sorting of biological cells, and
- The alliance of MEMS and time-frequency, targeted towards a new generation of miniature high-stability atomic clocks based on MEMS technologies.

Signature of the Collegium agreement: from left to right Bernard CRETIN (Director of the ENSMM) Christian ENZ (Director of the IMT/EPFL) Philippe PIERI (CNRS), Philippe Gillet (Interim President of EPFL), Jacques BAHI (President of the UFC), Abdellah EL Moudni (Vice- President of the UTBM).

Lab course session in the clean room of FEMTO-ST, with EFPL Master students (February, 2013).

The educational actions will permit :
- The implementation of new joint high education modules (master level) between French and Swiss partners,
- The joint organization of thematic workshops, and
- The organization of SMYLE summer schools to disseminate the research results and stimulate innovation.

Finally, the innovation actions will permit :
- The creation of a club of industrial partners,
- Organization of seminars to promote industrial partnerships, and
- Stimulate dissemination actions and technology exploitation.

The research program concerns the strategically important field of "Smart Systems", combining the potential of two major research institutions in the field of Engineering Sciences, and it aims to establish an international leadership in topics with a strong potential of applications.

Contact

Christophe Gorecki: christophe.gorecki@femto-st.fr

A novel educational program : Master Degree of Engineering (CMI)

Next to its role in Research and Interactions with the industries for innovation and transfer, another major strategic involvement of the institute has been chosen in the direction of the education programs, from the Bachelor degree to the Master degree.

In 2013, FEMTO-ST has started to support two new education programs (in Physics and in Mechanical/Electrical Engineering) designed over 5 years, in close connection with its research areas. These programs are part of a national initiative named CMI ("Cursus master en Ingénierie") and are proposed at the University of Franche-Comté. CMI is a national label delivered by the "Réseau FIGURE", a network of 17 French universities for engineering (PIA IDEFI). It consists in Masters of Excellence for Engineering and Research. It aims to provide a series of complementary courses (disciplinary knowledge but also societal, cultural, environmental, and entrepreneurial skills) to prepare students for careers in either industry (telecommunications, transport, energy, health, aeronautics, aerospace...) or academia, through very close interactions with Research all along the five-year education program (thus promoting the continuation with a PhD after the Master degree). 3 projects and 3 internships are part of the mandatory syllabus: (Engineering discovery, Academic Lab Research experience, Industry internships).

Contact

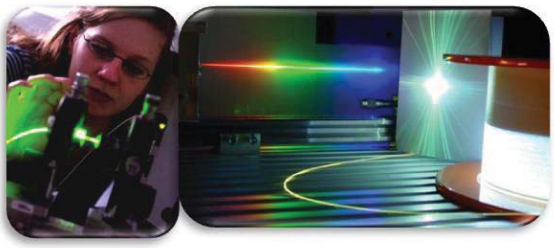
Maxime Jacquot: maxime.jacquot@univ-fcomte.fr

The first two CMIs concerned by the research activities at FEMTO-ST, named PICS and S^3, (Smart Systems and Structures) have opened (for undergraduate level) in 2013:

1) CMI PICS provides a comprehensive program of courses covering the theoretical, experimental and engineering aspects of photonics, micro/nano technologies, time-frequency metrology, information theory and complex systems. It is designed to cover a selection of topics at the interface of physics and engineering sciences. It is open to students with undergraduate physics or electrical engineering degrees.

2) CMI S^3 provides a comprehensive program combining electrical and mechanical engineering inside smart systems and structures embedded in objects with new functionalities. It is open to students with undergraduate mechanics or electrical engineering degrees.

Considering the success in the number of students applications for our CMIs in 2013, the institute has decided to push further this educational strategy, with the preparation of two additional CMIs. One is centered around the field of Energy, and the other addresses Computer Science.



frec|n|sys

frec|n|sys : a high added value start-up producing RF-MEMS devices for strategic and harsh environments

Frec|n|sys designs, fabricates and commercializes passive RF components based on elastic wave transducers and acoustic vibrations. Created officially in early 2013 after one and half year growth in the Innovative Company Incubator of Franche-Comté (IEI-FC), frec|n|sys (for Frequency Components and Systems) finds its roots partly in the FEMTO-ST Institute – Besançon, where the company's CEO has been working for more than 20 years and in the industrial history of the Thomson group, more specifically its division in charge of surface acoustic wave filter and sensor development. LPMO lab and further FEMTO-ST has been collaborating for 12 years across a common laboratory (LPMX), first with the Thomson/Thales Microsonics compagy and then with the TEMEX compagny. As the latter did stop its technological activities in 2007 when merging with the Rakon group, the Franche-Comté University benefited from European funds (FEDER), national resources (CNRS, OSEO, DIRECCTE) and the support of local authorities (Département, Région, Agglomération, etc.) for purchasing a complete industrial fabrication line dedicated to SAW devices (the so-called "QuartzTech" pilot line). Transferred from Sophia-Antipolis and redeployed in Besançon in 2009/2010 within the MIMENTO platform, this equipment was restarted successfully in 2011, producing the first industrial surface acoustic wave (SAW) devices in Besançon.

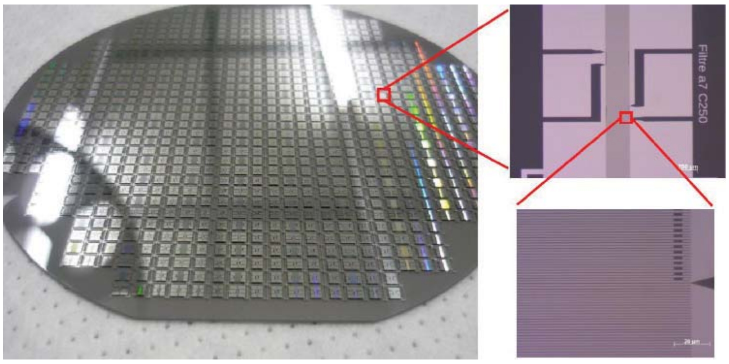
The creation of frec|n|sys was initiated the same year and set on track after a 1½ year incubator/training period. The company is now composed of 5 team members covering all the short term needs of the company (Production, R&D, Computer Resources and Business).

The company is exploiting technological equipments for the fabrication of SAW resonators, filters and sensors addressing all applications requiring such components.

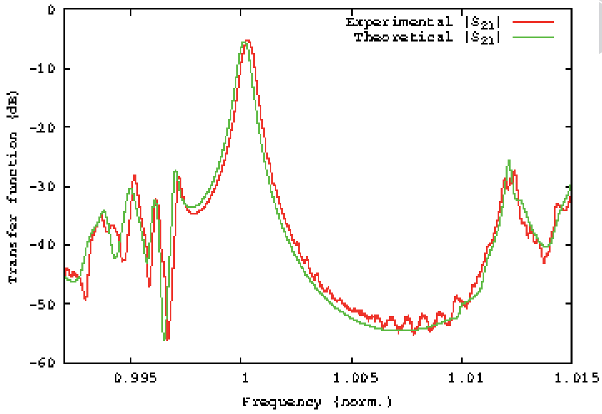
This technology platform is equipped with high-precision non-contact lithography machines, thin layer deposition and surface micro-machining facilities (wet and dry – plasma aided – etching) and several characterization set-ups. This technology allows frec|n|sys to manage prototype and small series fabrication but the company ambitions to acquire more experience for producing larger series.

In that context, the company is developing new competences in the field of MEMS, particularly for the fabrication of composite materials combining piezoelectric thinned wafers bound to any single crystal wafer. This activity is developed in close collaboration with FEMTO-ST. The company benefits from a solid experience in the design and fabrication of such devices for prototyping and small series.
The theoretical design and analysis tools it uses for developing its activity are unique and enable us to address almost any wave guide configuration. frec|n|sys also currently integrates facilities and know-how for on-trench ferroelectric domain engineering using $LiNbO_3$ and $LiTaO_3$ substrates for both RF and optics markets and acts as a foundry for non-standard materials and related technologies.

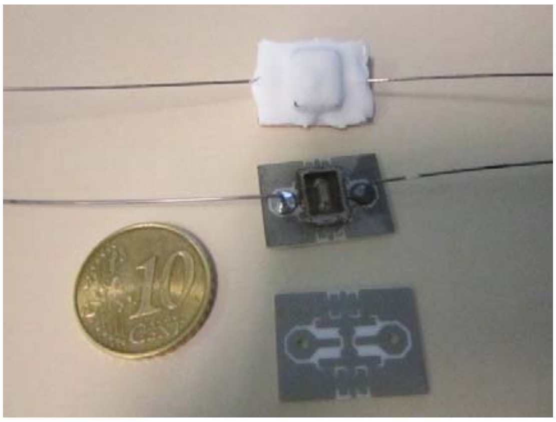
More specifically, the company dedicates a strong R&D effort for the development of battery-less and wireless sensors capable to operate under very harsh environment, particularly high temperature conditions with a target at 1000°C. In that pursuit, the company exploits results based on SAW sensors designed to operate above 500°C (700°C demonstrated) for which a new solution for sensor/antenna assembly has been developed and protected (result of European project SAWHOT).



Collective fabrication on a 4" Quartz wafer and details of the filter



Theory/experiment assessment of filters fabricated by frec|n|sys



Harsh environment sensor developments : Advanced packaging developed by FEMTO-ST in the SAWHOT project, and further developed by frec|n|sys toward industrial products - EC Patent application #12 53568

The targeted markets are first Defense and Aerospace for which requirements are particularly severe and challenging, and also industrial equipment instrumentation and metrology for harsh environment in a B-to-B approach. The company has developed commercial relations with local (AR Electronique, AUREA, Photline, SENSeOR), national (RAKON, Avenisense, SAFRAN) and even international companies (EPCOS, GVR, FOMOS) for which frec|n|sys acts as a design center, a manufacturer and/or sub-contractor along the scenario. The company has been among the laureates of the French High-Education and Research Ministry (MESR) contest for innovative industry creation in 2013 (CNCEI). It is also supported by the European initiative Cowin. Expecting the break even for 2015 with a turnover of about 1 million €uros (with 50% for harsh environment markets), frec|n|sys develops new MEMS solutions and ambitions to propose 150 mm-based technology in 2016-2020 with break-through components based on composite wafers (thin or thinned piezo-layer on various substrates) for acousto-electric devices and advanced systems.

Contact

Sylvain Ballandras, CEO, frec|n|sys SAS,
18 rue Alain Savary, 25000 Besançon
Tel.: +33 (0)3 8125 5363 – Cel.: +33 (0)6 1264 1434
e-mail: sylvain.ballandras@frecnsys.fr
Web site: http://www.frecnsys.fr/

FEMTO Engineering setting-up

June 2013 was created FEMTO engineering, an ambitious and risky project initiated by FEMTO-ST. With the creation of this center for technological developments, FEMTO-ST intend to generate economic activity, to keep in Franche-Comté PhD and engineers of excellence and to create expertise set on some breakthrough technologies from research of FEMTO-ST:

- Time-Frequency
- Energy
- Optics
- Micro & Nano-Technologies

FEMTO Engineering aims at being internationally recognized as a center of expertise for these key technologies with a regional impact and also an impact over the whole Jura Arc, including Switzerland and especially towards SMEs. Its expertise relies on FEMTO-ST Institute's know-how and technological resources.

FEMTO Engineering offers innovation solutions through industrial partnerships as FEMTO-ST is in contact with many industrial companies, in particular SMEs, which are interested in high technology developments or know-how of a high-level. Those developments are not academic research but flow directly from it.

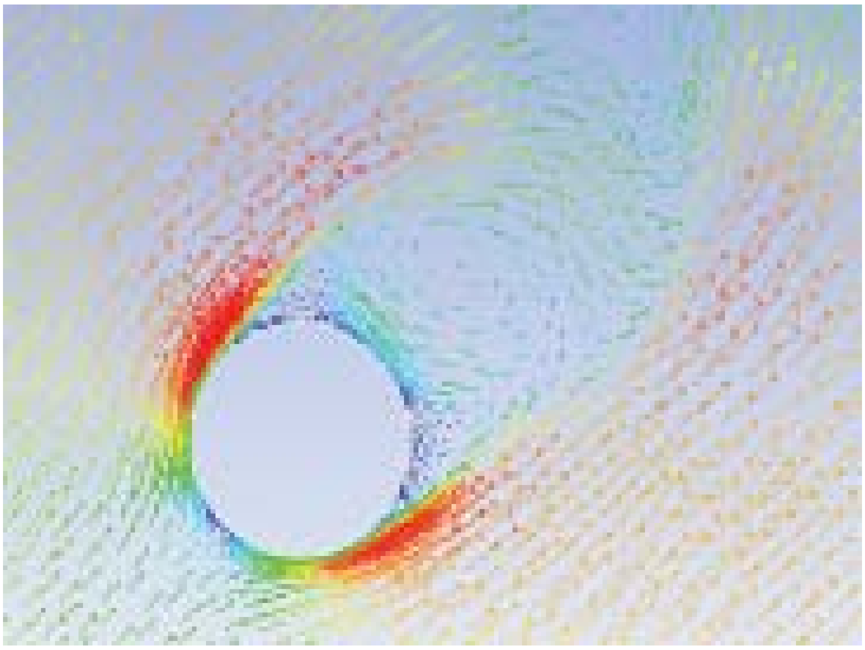
Furthermore, it allows what is «produced» by the laboratory to have a socio-economic impact.
Thus, if the research laboratory is indeed based on a scientific activity ("R" segment), an extension dedicated to the "D" segment allows to consider a comprehensive R & D range such as:
- Development of technologies from the laboratory (called proprietary technologies)
- Opportunity for industry to benefit from high-level specific developments

This extension is naturally in close relationship with the industrial sector, and it is:
- operated by doctors and engineers, some of which, occupying essentially technological key functions, are taking benefit from permanent contract to maintain core competencies
- immersed in the laboratory, to benefit from equipment and to share with permanent researchers
- largely driven by the laboratory and its guardianship, who are able to identify outlines and to set goals

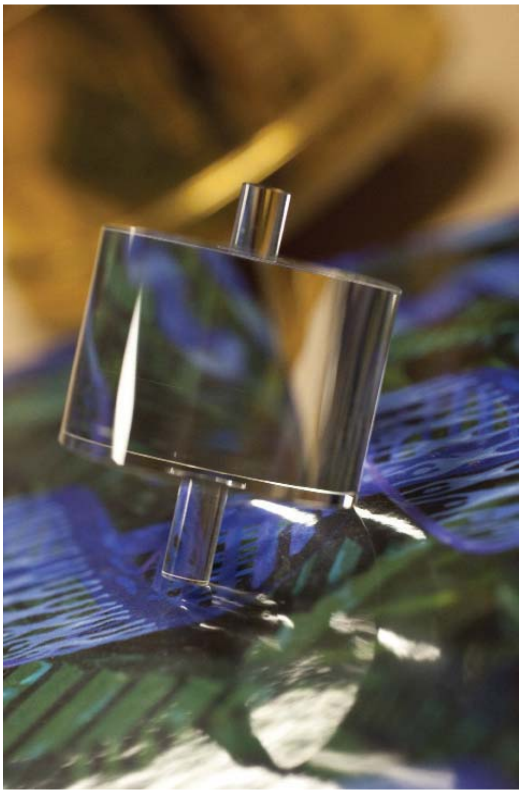
To allow the setting up, a feasibility study was done over a year alongside the work initiated within the scope of the Regional Strategy for Innovation on evolution of technology transfer at a regional level.
In view of this study, the University of Franche-Comté (UFC) decided to create a partnership foundation, Franche-Comté' Innov (FC' Innov) to provide a legal framework to the FEMTO Engineering project, with a strong support of the Region of Franche-Comté.
If starting this partnership foundation is mainly with the FEMTO-ST Institute, it is important to emphasize that it is be open to all UFC Laboratories.

By 2015 a dozen of jobs, mostly engineers or doctors, are expected.

Contact
Gregory Haye: gregory.haye@femto-st.fr



Fluid mechanics: CFD modeling



An ultra-stable cryocooled sapphire oscillator

Percipio Robotics S.A.

Created in February 2011, Percipio Robotics S.A. is a spin-off from FEMTO-ST Institute. With a wide know-how and expertise on robotic micromanipulation and micro-assembly, our activity as robotic designers and subcontractor enables to use this technology in industrial and research applications.

Percipio Robotics S.A. is already working with many customers on robot design, assembly subcontracting, or micro device fabrication and has launched in 2013 a new product for watch industries.

Currently, watchmakers work in complex conditions, a magnifying glass under the eyes, bent on their desks to assemble the delicate mechanisms of precious timepieces. This job is made all the more complex due to the technological evolution of watches requiring more complex and accurate operations, and also to economic and productivity constraints.

Considering that high precision assemblies can be reached by exploiting both robotic precision and human cognition, Percipio Robotics has launched in 2013 the CHRONOGRIP, a compact robot machine dedicated to helping the operator in high precision manipulations. The manipulations are done by a dexterous microgripper placed on high precision positioning stages controlled with an original interface: the CHRONOGRIP is actually driven using an innovative natural interface with the traditional gesture of the watchmaker, a way to control this high accuracy robot "at your fingertips".

Developing our business, we are also investing in research projects with industrial and academic partners, and especially with FEMTO-ST institute, to go forward on the path to innovation.

CHRONOGRIP: micro-assembly systems controlled via different tactile or intuitive interfaces

Contact

David Heriban: contact@percipio-robotics.com

Aurea

http://aureatechnology.net/en/

AUREA Technology is a company created in 2010 by Dr. Johann Cussey, Dr. Frederic Patois and Jérôme Prieur. Dr. Cussey and Dr. Patois received their PhDs in Engineering from the University of Franche-Comté in 2005. Their research activities in the Optics dept. of FEMTO-ST, OPTO group under the supervision of Dr. Merolla, dealt with novel Quantum Key Distribution (QKD) methods intended for fiber communication networks. Later on, they brought essential photonic hardware contributions to the worldwide first plug & play commercial QKD-based encryption system for fiber networks.
As experts in photonic technologies and quantum applications they decided to create a company based in Besançon, AUREA technology. This innovative company provides now on the worldwide market a new generation of high performance and easy-to-use Single Photon Counting Modules. Such products are enabling scientists and engineers to measure very low light level down to a single photon. As a leading maker of innovative optical instruments, AUREA Technology provides the "best in class" Near Infra Red Single Photon Counting Module and also the first "all-in-one" Near Infra-Red Time Correlated Single Photon Counting TCSPC Module.

AUREA Technology works closely with its scientific and industrial customers to meet today's and tomorrow's challenges in photon counting. Its product addresses various applications, the biotech area, nanotechnology, life sciences, optical networking, bio-medical, environmental and aeronautics industries. Among many others, its customers include famous organizations such as the American Department Of Defense, OKI, EDF, Rochester. In recognition of its Research and Development efforts, AUREA Technology has already been distinguished several times: (1) OSEO award (2011), (2) Young Innovative Company award ("JEI") (2011), and (3) "Photon de Bronze" award in 2012, a French prize for the most innovative realizations in photonic.

Contact

Johann Cussey: info@aureatechnology.com

Highlights of the theme 2PC (Polymers and loaded Polymers)

Applied Mechanics

During the year 2013, the PLP (Polymers and Loaded Polymers) research activities grew in importance at the FEMTO-ST Institute by developing new approaches while finalizing ongoing projects. This growth in activity includes in particular the NewPIM project focusing on injection molding of metallic powders. This successful project has just been completed, motivating a new follow-up project. In continuity with the first one, the main evolution consists in adding different powder functional materials. By including additional charges in the mixtures, we expect to attaching specific new functions to the designed materials (functionalization) which will open up new horizons in the development of integrated functions in matter. Moreover, new partnerships have been developed with the large European company Erasteel enabling us to investigate magneto caloric powders. Such developments will lead to new technologies applicable in the field of magneto caloric coolers. These new chillers based on magnetic refrigeration can be used in the fields of micro and nanotechnology, for example, thanks to their very high coefficient of performance.

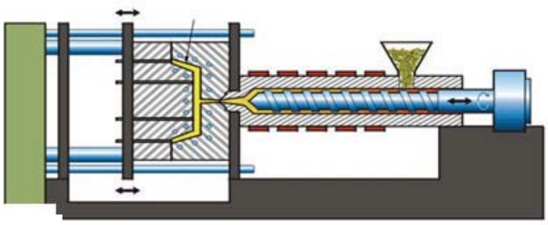
Furthermore extensive work just started on lead nanoparticles as well as carbon nanotubes. Two PhD theses have begun, one addressing the feasibility of strengthening and functionalizing complex parts, and the other targeting the development of consistent and efficient functional blends.

Meanwhile, a new field has been created with the design and manufacture of turbine blades for use in aircraft engines. Because of its internationally recognized expertise, the research theme has become a partner of the CORAC project led by the SNECMA and SAFRAN Companies. This new area will focus on the realization of super nickel-based alloy components and in this context, the PLP group is currently responsible for the definition, design, and realization of prototype turbine blades for future reactors.

Finally, new approaches for the manufacture of micro-components by hot embossing of polymers and filled polymers have been developed. Significant results have been obtained, leading to a solid international level. The PLP group has developed a new concept using flexible molds for rapid prototyping of microfluidic inserts, using the concept of the flexible mold from silicon wafers. As microfluidic circuits or nano-fluidic could be developed on flexible substrates, and then used for shape replication.

Contact

Jean-Claude Gelin: jean-claude.gelin@univ-fcomte.fr



Turbine blade developed at FEMTO-ST Institute

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Since 1995, the teams of the AS2M department have been involved in the micro-robotics and micro-mechatronics research field. In 2008, the AS2M department joined FEMTO-ST institute, and consists in the largest European team in the field of micro-manipulation and micro-robotics.

During the last decade, a lot of advances have been made concerning micro-manipulation, automation and the design of robotic systems for micro-handling or micro-manipulations. AS2M activities were recognized through many awards and, among them, the CNRS Bronze Medal, triple world champion in non-contact robotics and also two "Gold Micron" in the industrial trade-fare Micronora. This know-how concerning micro-manipulation has been recently transferred to the spin-off company of the AS2M department: Percipio Robotics. Currently, the department is mainly focused on new challenges concerning micro-mechatronics, automation and instrumentation at the micro-scale and the micro/nano-robotic field for medical and biomedical applications.

These scientific results are based on a strong know-how regarding the mastering of motion control in micro-scale. This mechatronic topic, addresses two major scientific challenges:
- Dynamics modelling and innovative control for high precision motion control systems.
- Integration and optimal design for micro-mechatronic devices.

Control the motion at the micro-scale When control engineering meets micro-systems and material sciences

AS2M (Automatic Control, µ-Robotics and Pronostic)

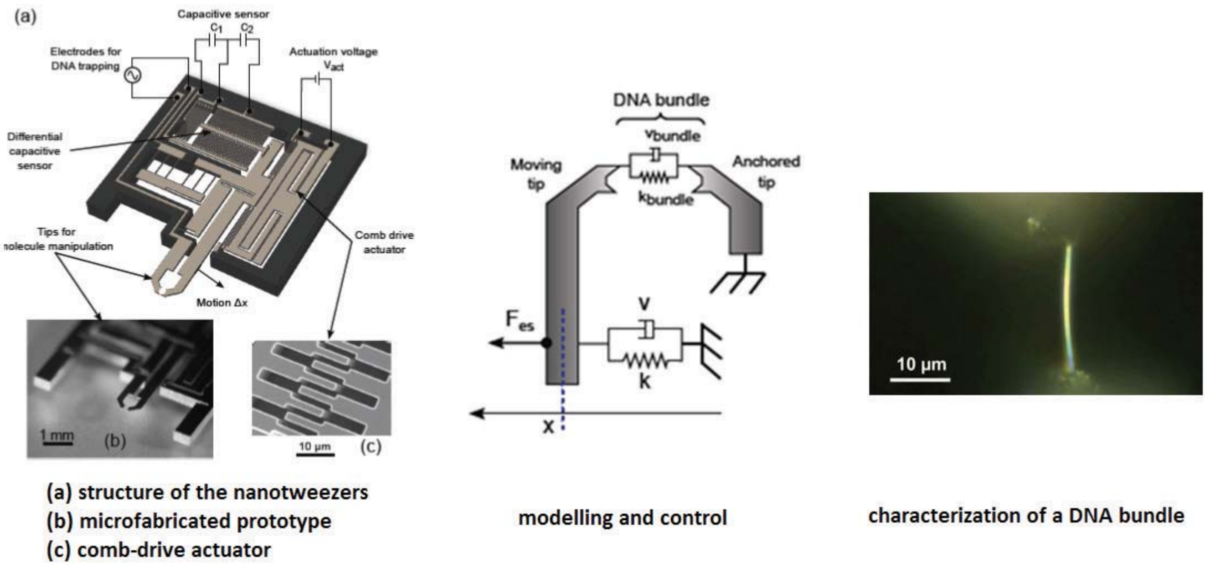
One of the best results illustrating the first scientific challenge on motion control at the micro-scale is the robust control of electrostatic nano-tweezers for DNA characterization (*Upper Figure*). This work, done in collaboration with LIMMS and IIS of the University of Tokyo, Japan, concerns the mechanical characterization of DNA bundles immersed in enzymes. The stiffness of DNA molecules is so small (30 µN/m) that it cannot be measured using mechanical methods even with the most advanced micro-fabricated grippers. Reducing the size of the nano-tweezers is limited by the capabilities of clean-room processes. Moreover, a smaller device would be so fragile that it could not be used concretely for manipulation tasks. Feedback control is one way to modify the dynamic and static behavior of a mechanical system. Our original approach consists in designing advanced feedback control methods enabling to virtually reduce the nano-tweezers' stiffness and thus improve measurement sensitivity. This multidisciplinary approach has yielded performance well beyond the performance achieved by mechanical optimization.

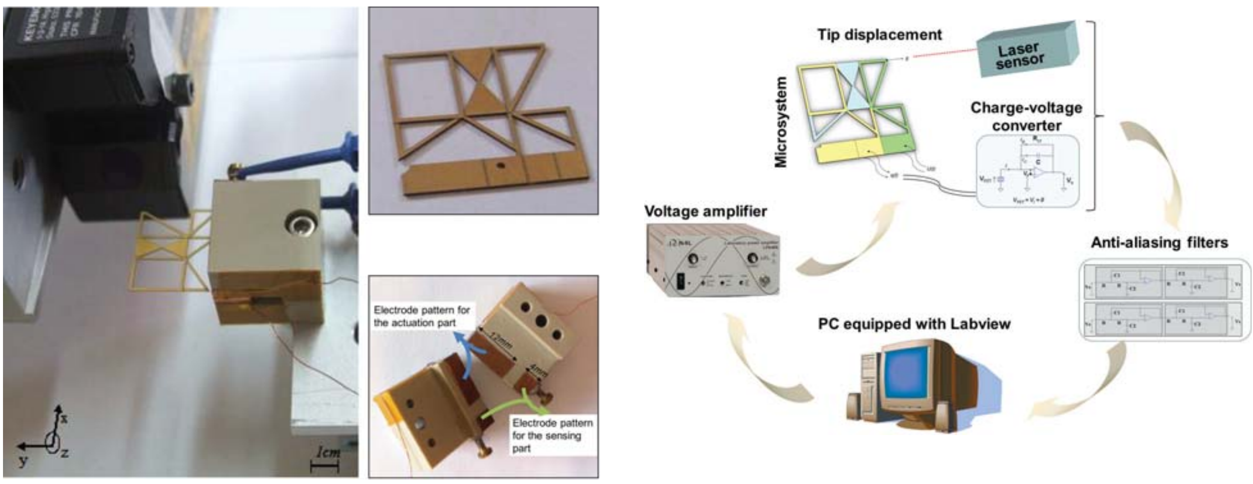
An example of the second scientific challenge dealing with motion control at the micro-scale is the optimal design of structures integrating piezoelectric materials used as sensor, actuator and mechanical structure.

Contact
Michael Gauthier: michael.gauthier@femto-st.fr

This work was done in collaboration with the Interactive Robotics Laboratory of the CEA LIST, France. *The lower Figure* is an example of a bulk PZT optimal structure building a micro-gripper. The geometry was optimized considering mechanical, electrical and control criteria using a genetic algorithm, a block method and a finite elements procedure. The feedback control of the structure is based on PZT integrated and distributed actuators and sensors, a strain state-space observer and an hysteresis compensation controller. This multidisciplinary mechatronic design approach gives integration and performance rates far beyond those found in the literature.

Robust control of electrostatic nanotweezers for DNA characterization.





Optimal design of structures integrating piezoelectric materials used as sensor, actuator and mechanical structure. Example of a bulk PZT micro-gripper (left) and its control architecture (right).

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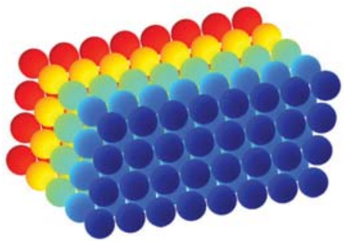
Phononic crystals

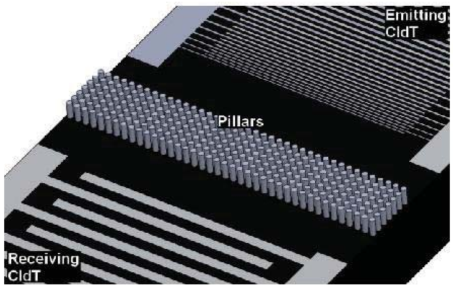
MN2S (Micro Nano Sciences & Systems)



What is phononics ? – Just try and imagine a forest where all trees are planted following a perfectly periodical arrangement. Further assume the diameter of all tree trunks are the same. You have just figured out a two-dimensional periodical structure. Try now and picture a path in this forest. Someone walking along it would be surprised to discover that the sounds he hears are distorted by the time they reach him. Listening to the music played by a nearby orchestra, he would distinctly hear the low tones of cellos or the high tones of violins, but would realize that a full range of the audible spectrum is missing! This apparent attenuation of a certain part of the spectrum is a signature of a **band gap for sound**. Such a forest is an example of what physicists call a **phononic crystal**. Artificial media mimicking natural crystals could lead to the design of surprising phononic circuits.

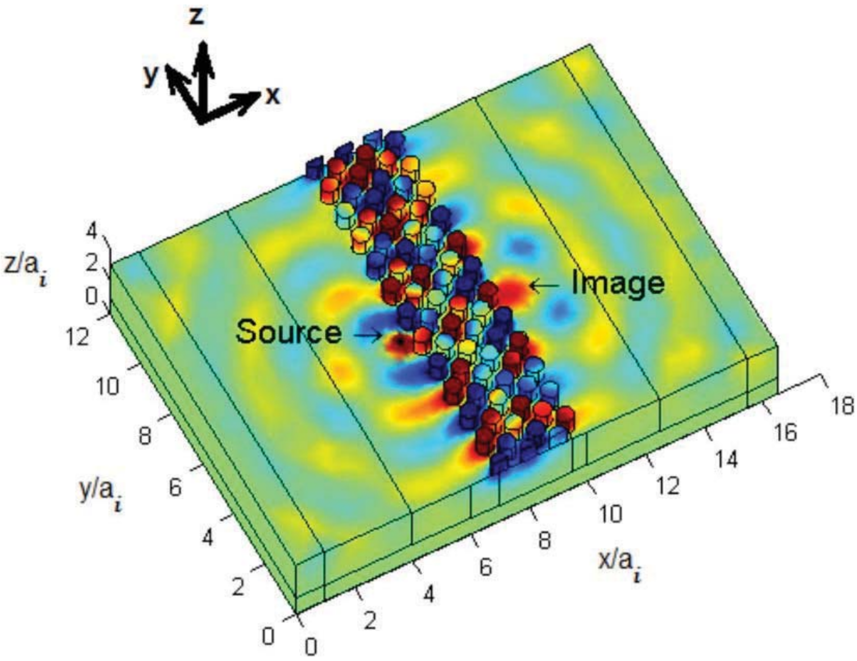
The **Phononics group** has been exploring ultrasonic phononic crystals with millimeter-size lattice constants since 2002. Since the lattice constant is commensurate with the wavelengths that are most influenced, ultrasonic phononic crystals immersed in water operate at megahertz frequencies, well within the range of medical ultrasound applications. We have recently designed phononic crystal diffraction gratings that experimentally achieve almost 100% diffraction efficiency[1]. They can thus steer and disperse an ultrasonic acoustic beam without losing a bit of the incident power. We could recently discover a novel family of surface acoustic waves that are trapped by a deeply corrugated solid-liquid interface and design perforated membranes that are opaque to ultrasound[2].

At a much smaller scale, we are developing **microscale phononic crystals**. These tiny artificial crystals are fabricated inside the MIMENTO technology centre, by either perforating small holes or growing mechanical resonators on a surface. Microscale phononic crystals have gigahertz operating frequencies. Of particular interest to us is the propagation of surface acoustic waves and the design of waveguides. We have recently studied phononic crystals of pillars on a surface, since while they have phononic properties very similar to crystals of holes, they can store mechanical energy as they enter resonance, trapping and delaying waves very efficiently. We could demonstrate that pillars turn the surface into a metamaterial supporting unusual waves: instead of diverging away from the source, they are refocused by the crystal, a phenomenon known as all-angle negative refraction. Metal pillars distributed periodically on the surface also form a highly efficient waveguide for surface acoustic waves. As a further surprise, we found that the band gaps of resonant pillars are found to resist a rather high degree of randomness[3].



Schematic of a phononic crystal made of metal pillars deposited on a piezoelectric surface. A pair of interdigital transducers (IDTs) are used for the generation and detection of surface acoustic waves.

Research in phononics will continue both along familiar and new directions. "There's plenty of room at the bottom" Richard Feynman said, an advice we intend to follow literally: by downsizing phononic crystals we hope to translate them into the nanoworld, where we could play with artificial periodic clusters of molecules or nano-objects. Phononics is still a brand new field and most of its story still remains to be told.



Acoustic displacement field of a point source and of its image across a pillar-based phononic crystal flat lens.

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Contact

Abdelkrim Khelif: abdelkrim.khelif@femto-st.fr

Cryogenic Sapphire Oscillator : The stability that comes from the cold

TF (Time & Frequency)

The implementation of ELISA in Malargüe (Ar) in the Deep Space Antenna Station (DSA3) of the European Space Agency (ESA) and the success of the ULISS project represent the outcome of more than fifteen years of research on cryogenic oscillators lead at the Time and Frequency Dpt. of FEMTO-ST. The Cryogenic Sapphire Oscillator (CSO) technology is currently the only one able to provide relative frequency instability better than 1×10-15 for integration times from 1s to 1 day. Such a performance is needed for some applications as space, radioastronomy (VLBI), applied and fundamental metrology and physics.

As in a grandfather clock, the CSO is based on a “pendulum”, which fixes the output frequency. In the CSO, this “pendulum” is a cylindrical electromagnetic resonator machined in a high quality Al_2O_3 monocrystal (Sapphire). At low temperature (6 K typically) a 10 GHz wave launched in the resonator will undergo one billion cycles before extinction due to residual dielectric losses. This property ensures ultra-high frequency stability.

In our first experiments the resonator was cooled in a liquid helium bath. This solution is obviously incompatible with real applications outside a well-equipped metrological lab. We thus developed for ESA an oscillator based on a closed cycle cryogenerator. This system is autonomous and demands only a light maintenance.

In April 2012, our first CSO, codenamed ELISA, was installed in Malargüe (Ar). ELISA was conveyed by air to Buenos Aeres, then by truck to Malargüe. Eventually, about 30 km on an unpaved track enabled to reach the ESA station. This instrument works continuously and is used to verify the functioning of the Masers and the antenna synchronisation systems. It will be used as a demonstrator in a next ESA mission in 2014. The ULISS project is a part of a voluntary economical valuation of our CSO technology, for which a “niche market” exists.

A new CSO: ULISS was specially designed to be transportable by road. It has been compared and tested in various laboratories and industrial companies throughout Europe: CNES, LTF (Neuchâtel), SYRTE (Paris), VLBI Geodetic Observatory Wettzell (Germany), Onsala (Sweden). The objective is to demonstrate in the potential user's sites the performances of this new technology and to better understand the needs associated with each specific application. Other journeys are planned in 2014; in particular ULISS will be rented to the CNES for the final test of the PHRARO experiment instruments.
Another step towards the valuation of this instrument will soon be realized: an ANR Emergence project is in progress aiming at a drastic reduction of the electric consumption and a better control of the key technologies. Finally, a set of three cryogenic oscillators will constitute one of the ultra-stable references of the OSCILLATOR-IMP platform.

ULISS project web site : **http://www.uliss-st.com/**

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Contact

Vincent Giordano: vgiordano@femto-st.fr

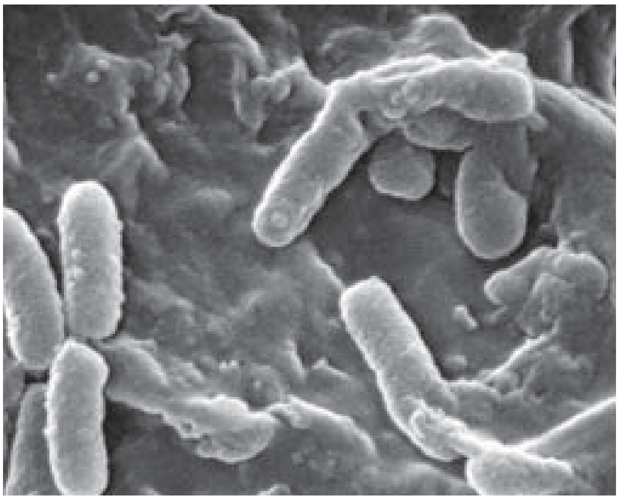
Implementation of an Cryogenic Sapphire Oscillator in the ESA ground station in Malargüe (Argentina)

Bioinformatics

DISC (Computer Science for Complex Systems)

Between 1997 and 2009, 250 patients of Besançon hospital, in France, have been infected by an epidemic strain of the opportunistic pathogenic bacteria called *Pseudomonas aeruginosa*. The phenotypic variability of the pathogen under scrutiny has led to the hypothesis of some genomic modifications during the epidemic. The validation of this assumption requires to sequence twenty strains and to design new bioinformatics tools, in order to discover these genomic mutations[1]. Two strains (dating from May 1997 and April 2008) have already been sequenced, annotated, compared, and sent to the NCBI server (National Center for Biotechnology Information). The other strains are about to be sequenced. Using original computing methods, we have demonstrated that the twenty genomes shared 6462 genes -- 163 of which being specific of the precocious strain while 420 genes were found in the late isolate only.

These preliminary studies validate both our newly developed tools and the initial assumption. We have shown that a given strain of *P.aeruginosa* evolves during the spread of the epidemic, notably by a large scale reordering of its genome. To do so, we have detected the genes location inside the original sequenced genomes using home-made ad hoc software running on the Mesocentre de Franche-Comté (France) computer facilities. The genes that are predicted to have changed location have then been grouped by similar functionality (so-called orthologous genes - that is, genes having a common evolutionary history). For the first time, such grouping gives us the possibility to determine the core genome of this bacteria - the collection of genes specific to the *P.aeruginosa* species. Hence, this highly significant biological data, obtained thanks to the FEMTO-ST original algorithms, will lead to a better understanding of the specificity of this bacterium and of the evolution of its genome over time. This knowledge will eventually help bacteriologists fight against this pathogen.



A microscopic view of P.aeruginosa

After characterizing the genomic recombination within this cohort of genomes, we have inferred an accurate phylogeny (evolutionary relations between these strains) based on all the nucleotide mutations of the core genome, and the specificity of each strain regarding the core genome has been represented using new algorithms developed in our department. We are now looking for genes of virulence and of antibiotic resistance on the one hand[2], and studying the remarkable events due to the genomic plasticity of this bacterial species, on the other hand. In a second stage of this original approach for the study of a nosocomial disease, we intend to integrate 70 other non-assembled genomes of various strains of *P.aeruginosa*, in order to improve the understanding of the specificity of the epidemic strains from Besançon hospital, enlarging the means to fight *Pseudomonas* epidemics. Such a bioinformatics strategy will finally be applied to other pathogenic species like those belonging to the *Mycobacterium tuberculosis* complex.

This project has required a strong collaboration between the DISC dept. of FEMTO-ST, the Mathematics Laboratory of Besançon (LMB), and Chrono-environnement Lab (Univ. Franche-Comté), as computing genes prediction and clustering of such a large set of genomes necessitate both to design methods related to algorithmic of words and big data.
These algorithms have needed a deep statistical analysis of DNA sequences, while the association of a biological functionality to each cluster of orthologous genes (like virulence or resistance) requires the very specific expertise developed by the Chrono-Environnement Lab.

Comparison between our two strains

Contact

Christophe Guyeux: cguyeux@femto-st.fr

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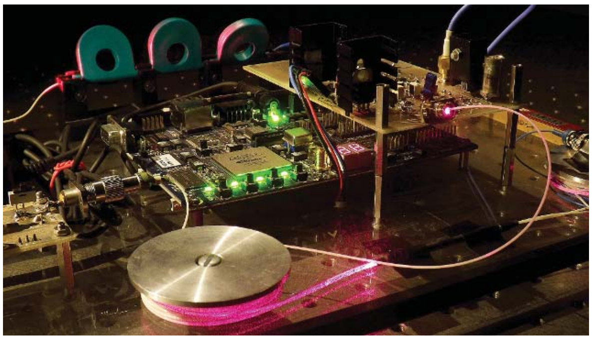
Brain-inspired photonic computer

Optics Dept. P.M. Duffieux



Optoelectronic setup demonstrating photonic Reservoir Computing

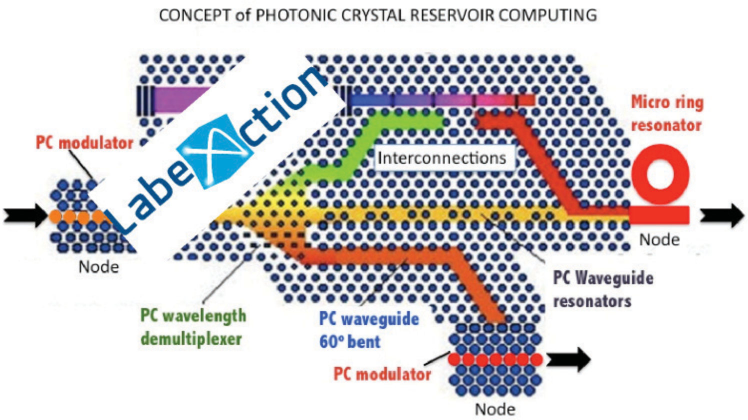
Over the last 15 years, FEMTO-ST has acquired an international expertise in the experimental and theoretical study of complex motion (among which high dimensional deterministic chaos) exhibited by a particular class of dynamical systems, **nonlinear delay dynamics**. These extremely rich and complex oscillators are particularly suited for photonic implementation. Initially investigated for chaos-based high speed physical layer cryptography for fiber optics communications, the approach has also been used to demonstrate another practical application of these photonic nonlinear delay oscillators: extreme high spectral purity microwave oscillations for Radar applications with enhanced detection capabilities.

More recent developments on the same complex photonic delay oscillators have tried to address, through their underlying complexity, a novel brain-inspired computational paradigm. This novel paradigm was first proposed in the early 2000 as an evolution of the standard neural network computing concept. It is now known as Echo State Network, Liquid State Machine, or Reservoir Computing.
In the framework of a recently achieved European project PHOCUS[1], the research at FEMTO-ST led to two important scientific results, highlighted and/or published in high reputation journals: a practical result consisting in the first **photonic Reservoir Computer**[2] ; and a fundamental result as the first experimental demonstration in delay systems of so-called **Chimera states**[3]. These Chimera states consist of surprisingly complex motions, which were only predicted in the early 2000, for complex networks of oscillators similar to the ones used in conventional neural network computing.

Implementing these nonlinear delay oscillators through the use of high speed photonic components developed for fiber optics telecommunication, results in brain-inspired photonic processors that could enable the execution of high complexity computational tasks at very high speed and with learning capabilities that would outperform our current digital computers. State of the art speech recognition accuracy has already been demonstrated with a real optical system at a rate greater than one million words per second. Various complex benchmark tasks have been tested, such as speech recognition, real time complex data analysis, forecasting of complex phenomena. It is worth noticing that before our very recent optical implementation, this novel "Reservoir Computing" concept was essentially addressed through numerical simulations, thus making use of a "standard digital computer".

Neuromorphic photonic computing is currently explored at FEMTO-ST as a DEMO of the Labex ACTION project, with the aim to achieve within the next 7 years a photonic integrated chip providing such high speed, high performance, and universal, photonic computing capabilities.

These activities are also currently explored in a strongly interdisciplinary collaborative framework, *(i)* with the Energy Dept. to address accurate and preventive diagnostic of real world operation of Fuel Cell stacks, *(ii)* with the Mathematics Laboratory of Besançon to investigate the forecasting of real stock exchange time series data, *(iii)* with a medical research group of the INSERM to analyze high complexity electroencephalogram (EEG) signals, *(iv)* and with another team of the Optic Dept. to investigate the Photonic Reservoir Computing potential in the real-time control of a femto-second laser beam devoted to nano- and micro-machining for future nano-technology fabrication tools.



Contact

Laurent Larger: laurent.larger@univ-fcomte.fr

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The reduction of energy consumption represents one solution to decrease the emission of greenhouse gases. As refrigeration technologies consume more than 15% of global electricity consumption, the design of efficient refrigeration systems is a key issue. In this context, magnetocaloric cooling systems are a promising alternative to classical refrigeration systems since a magnetization-demagnetization process of magnetocaloric regenerators is directly used to perform the heat pumping. The magnetocaloric devices can reach very high efficiencies, which can be explained by the absence of a compressor, which allows to consider many opportunities for this emerging technology.

The magnetocaloric effect is an intrinsic property of ferromagnetic materials consisting in the creation or absorption of heat energy by the action of a magnetic field. This results in the heating or the cooling of the material, respectively when the field increases or decreases. Warming and cooling are both reversible and adiabatically achieved and the material temperature variation is maximal when the working temperature is equal to the Curie temperature of the material.

However, the direct use of the magnetocaloric effect is insufficient in the case of magnetic refrigerators equipped with Permanent Magnets (PM) because of the low intensity of magnetic fields generated and therefore the low temperature variation. For operation at room temperature, gadolinium, which is the most commonly used material in magnetocaloric applications, has a ΔT of around 3 to 4 Kelvin per Tesla. It is therefore imperative to improve this temperature difference. In order to obtain such results, an Active Magnetic Regenerative Refrigeration (AMRR) cycle is classically used; the aim of such a cycle is to create, by a succession of heat exchange between the material and the coolant, a temperature gradient along the material. This gradient is increased at each cycle to achieve the temperatures of hot and cold sources at each end of the system; this gradient can reach 10 to 30K.

Magnetic refrigeration

Energy

Applying its multidisciplinary expertise in many topics concerning the magnetic refrigeration (magnetism, electrical engineering, thermal, fluid flow...), the ENERGY Department of the FEMTO-ST Institute has decided that this research field will be one of its research priorities.

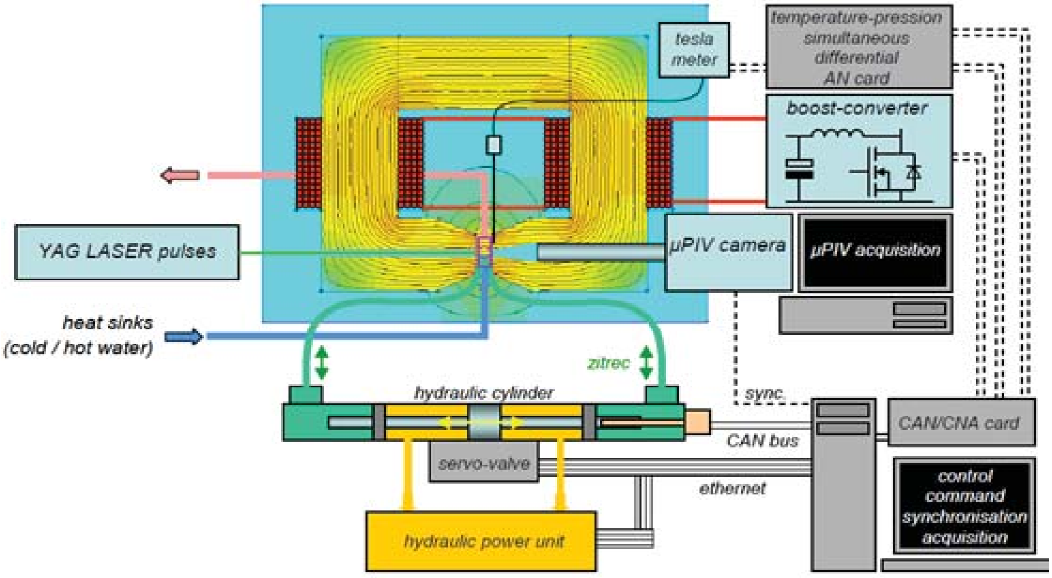
An original test bench has been designed at the FEMTO-ST Energy Department (*Upper Figure*). An electromagnet is sized to produce an alternative magnetic field in a large air-gap (flux density and frequency respectively in the range of 1 to 1.5 T and 1 to 50 Hz) and gadolinium plates (the magnetocaloric material) will be placed in this air-gap. A heat transfer fluid, such as Zitrec is used together with cold and hot micro-exchangers in order to transfer heat to the corresponding cold and hot sources. In addition, an optical channel is realized in the electromagnet in order to put a camera and to analyze the fluid flow between the plates of the regenerator. The hydraulic pump and the electric current flowing in the electromagnet windings are synchronized in order to achieve an AMR cycle. Finally, the test bench is equipped with several sensors (micro-thermocouple sensor, teslameter, flowmeter...) in order to characterize very precisely the AMR cycle, in terms of temperature, fluid flow, magnetic flux density etc.

An original numerical multi-physic model of an AMR has been developed in parallel of the experimental studies too. This model enables to compute the magnetic field in two ways: either with good accuracy by using 3D FEM software (at the cost of a great computational time) or by imposing an average value of the magnetic field to reduce computational time (reducing accuracy at the same time). Then, this model can be used to optimize the efficiency of the modeled device.

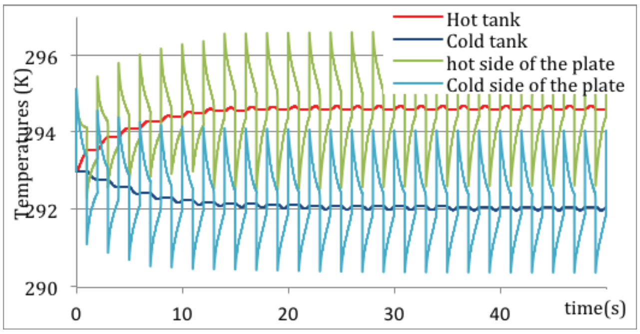
To summarize, two PhD theses, two industrial projects and one academic project supported by the Franche-Comte regional council, are presently under way on these topics at FEMTO-ST. Those different projects aim not only to propose new models and original test benches, but also industrial devices.

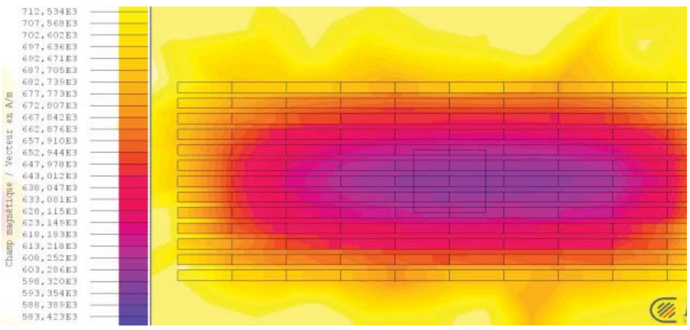
Contact

Philippe Nika: philippe.nika@univ-fcomte.fr



Scheme of the original test bench developed at FEMTO-ST Institute to characterize magnetic regenerators (AMR cycles)





Evolution of temperature (left) and Magnetic field (left) obtained with the model of AMR developed at FEMTO-ST Institute

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Success Stories

Interdisciplinary Research

Diagnostic, Prognostic & Health Management of Fuel Cell Systems[1]

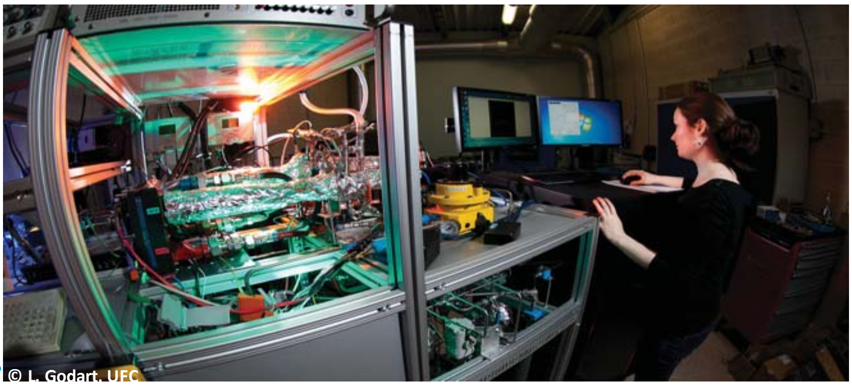
AS2M & Energy

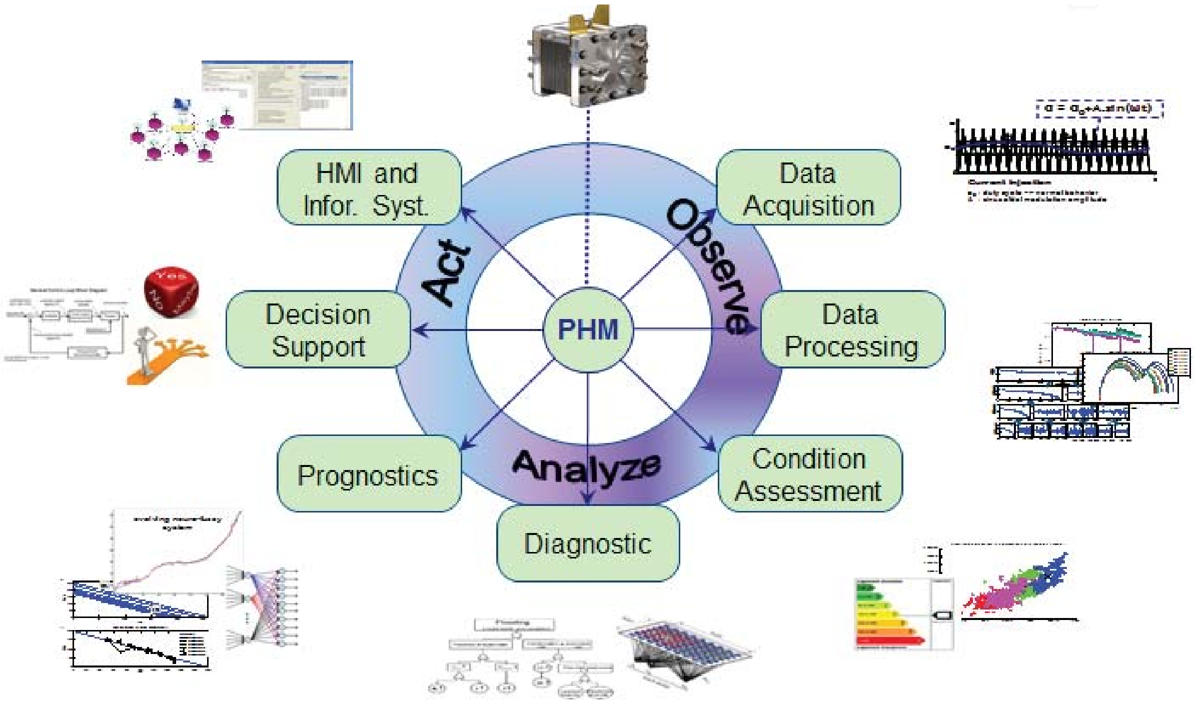
[1]*All these activities are also developed in the framework of the FCLAB research federation (FR CNRS 3539). http://www.fclab.org*

Fuel Cell Systems (FCS) appear nowadays to be promising and alternative energy converters in order to face the economic and environmental challenges of modern society. The applications can be found in the transportation area (electrical vehicles, trucks, airplanes, boats, forklifts ...) but also in stationary applications (power plants, coupling to renewables, electricity storage...). However, although this technology is close to being competitive, it is not yet ready to be considered for large scale industrial deployment. FCS must still be optimized, especially by increasing their limited lifespan (typically about 3000h today in transportation operating conditions, and even more in stationary operating conditions).

A key issue in this research area is the **development of diagnostic and prognostic algorithms**, able to operate on-line, with a minimum number of actual sensors. The Energy Department of FEMTO-ST was among the first labs in the world to start research activities on this topic in the early 2000[1]. Since these beginnings, many national and European research projects have been conducted on this topic by the researchers of FEMTO-ST (for low or high temperature fuel cells). Different diagnostic approaches have successfully been considered in these projects and developed by 9 PhD students: model-based approaches, knowledge-based approaches (fuzzy clustering, Bayesian networks...) and signal-based approaches (wavelet packets...). Different world patents[2] have also been generated on these topics, in strong relationship with major industrial partners. Hardware implementation of these diagnostic algorithms is a real issue in order to perform fast, efficient and accurate fault mitigation actions. Therefore, harmonic injection using the power converter has been considered, more recently neuromorphic photonic computing has also been explored with the OPTICS department of FEMTO-ST.

Additionally to these activities, a new area of science and technology has emerged over the last couple of years: **prognostic of fuel cell systems**. Indeed, considering the classical PHM (Prognostics & Health Management) cycle, prognostics is the next field after diagnostics for scientific and industrial developments. This new research area could emerge thanks to common activities[3] done between the AS2M and ENERGY departments of FEMTO-ST, in the framework of the CNRS research federation FCLAB. This field is also currently explored as a part of WP5 of the Labex ACTION project. In the last two years, one Franche-Comte Region and one national ANR project, led by FEMTO-ST, were started on this topic. Moreover, one European funded project was also started on this topic with leading industrials partners. The aim is not only to be able to estimate the remaining useful life of the fuel cell, but also to improve the capabilities of the developed prognostic tools by quantifying and controlling their inherent error of estimates. Several approaches are considered: a model-based prognostic tool based on a Bond Graph / Energetic Macroscopic Representation approach with parametric uncertainty, data-oriented prognostic tools by extending «signal» and «connexionist» approaches (like reservoir computing and neuro-fuzzy systems); model-based and hybrid approaches are also addressed. 5 PhD theses are presently under way on these topics at FEMTO-ST.





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Contact

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

Miniature Atomic Clock at FEMTO-ST: last achievements

TF & MN2S

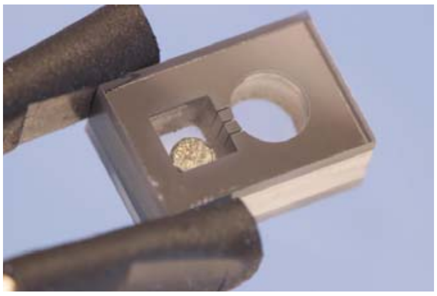
Today, thanks to the combination of a physics principle named coherent population trapping, microfabrication technologies and single-mode vertical-cavity surface emitting lasers (VCSELs), "pocket-size" miniature atomic clocks exhibiting a volume of 10-15 cm^3, a power consumption of 150 mW and a relative frequency stability of 10^{-11} at 1 hour and 1 day integration time can be developed. This technology allows to bring atomic timing in a volume, power and cost range previously covered by quartz oscillators. In this exciting and high-impact domain, FEMTO-ST, from 2008 to 2012, piloted a challenging FP7 collaborative project MAC-TFC (www.mac-tfc.eu) gathering the expertise of 10 European institutions. This project led to the demonstration of the first European miniature atomic clock. In such a clock, Cs atoms, confined in a micro-fabricated cell with a pressure of buffer gas, interact with frequency-modulated light from a VCSEL diode laser. Pumping the atoms in a so-called dark state, the atomic vapour transparency is increased and a resonance peak of laser power is detected at the output of the cell with a photodiode. The output signal is used both to control the laser frequency and to lock the 4.596 GHz local oscillator frequency driving the VCSEL to the atomic clock transition frequency.

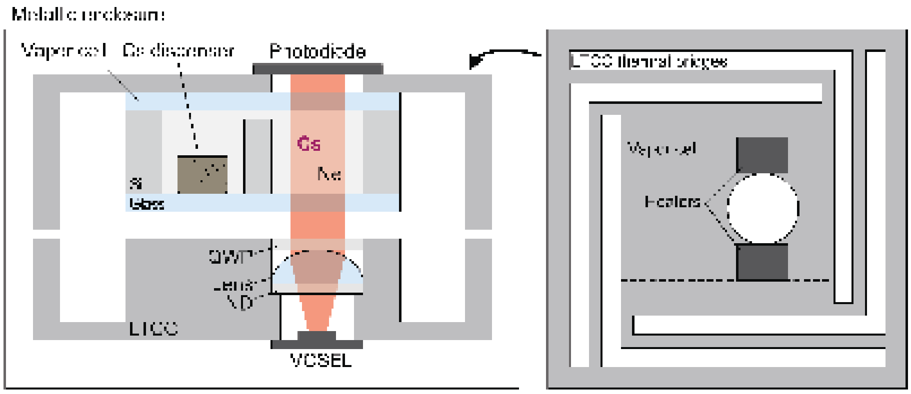
The heart of the miniature clock, achieved by FEMTO-ST, is a mm-scale micro-machined Cs vapor cell filled with a buffer gas. The first innovation of our technology, compared to other teams, is that Cs vapor is activated by laser heating of a Cs pill dispenser after the sealing of the cell. This ensures an improvement of the cell internal atmosphere stability, a stronger sealing of the atom "reservoir" and a better potential for mass production. A getter layer film, deposited inside the cell, allows to reduce significantly residual gas impurities in the cell. The second innovation is the use of a single neon (Ne) buffer gas configuration, canceling the clock frequency temperature-dependence at an operational temperature of about 80°C.

As shown in Figure, the clock includes a highly compact «physics package», made in LTCC ceramics (VTT Finland), that encloses the Cs cell, a VCSEL diode laser (Uni. of Ulm) resonant at 894.6 nm (Cs D1 line), micro-optical components, heating elements, sensors and magnetic shielding. The physics package is connected to control electronics that includes a low phase noise 4.596 GHz local oscillator and all servo controls for proper operation of the atomic clock.
Since 2011, stimulated by all these encouraging results, research activities have been pursued thanks to a project funded by ANR-DGA (ASTRID ISIMAC). This allows to provide innovative solutions for improved miniature atomic clocks, providing the base for a wide number of mobile applications including navigation systems, synchronization of networks, defense systems or secured time certification for banking data transfers. Additionally, 2 PhD thesis, funded by Thales Avionics and DGA/région Franche-Comté, are currently in progress. Eventually, new projects combining research and industrial transfer, supported by DGA Rapid and ISI OSEO programs, started recently in collaboration with 2 industrial companies.

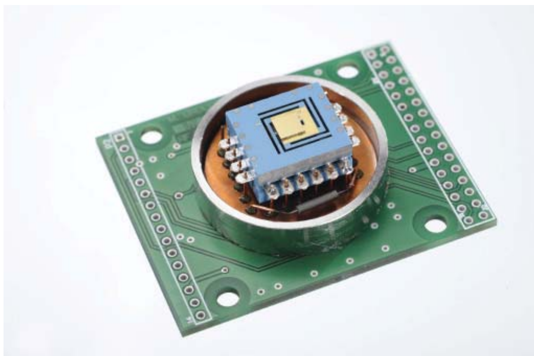
Contact

Christophe Gorecki: christophe.gorecki@femto-st.fr


FEMTO-ST Cs vapor microcells



The concept of LTCC physics packaging


Atomic clock physics package
(by courtesy of VTT.)

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*MAC-TFC partners: FEMTO-ST (Coordinator), EPFL, Uni. of Neuchatel, Uni. of Ulm, UT Wroclaw, VTT Finland, LETI/CEA, SWATCH SA, Oscilloquartz SA, SAES Getters
**ISIMAC partners: FEMTO-ST (Coordinator), SYRTE

Distributed intelligent MEMS (MicroElectroMechanical Systems)

DISC, AS2M & MN2S

Microelectromechanical systems (MEMS) have reached a position of design maturity and are therefore ready for the mass-production of micro-scale devices. Recent examples of mass-produced MEMS include accelerometers, inertial measurement unit (IMU) that are now included in airbag systems as well as in most of the recent smartphones or laptops, bubble ejection systems of inkjet printers or digital micromirror device (DMD), technology used for projection displays. As can be seen in these examples, MEMS can be used either as single elements (accelerometers, IMU) or they can be grouped and can act together to reach a global goal (DMD). The latter is called distributed MEMS.

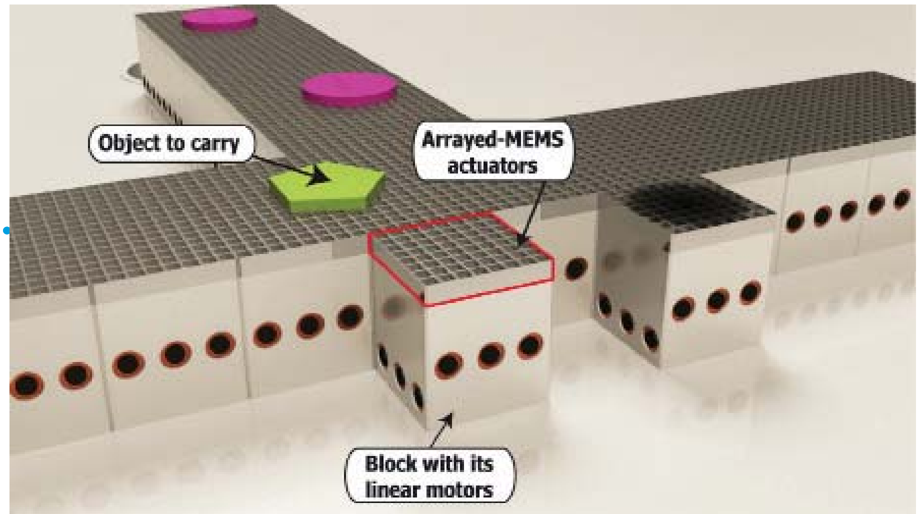
The main interest of MEMS is that they can be mass-produced, which is true for single MEMS as well as for distributed ones. It's therefore necessary to think of scalability up to millions of units when evoking distributed MEMS. Due to their small size, their low cost and the fact that they can be mass-produced, millions of units can be used in a very small space. For example, a volume of less than 1 m^3 of 1mm-diameter silicon balls has a number of nodes comparable to the Internet. This parameter requires paradigm-shifts both in hardware and software parts in order to scale.

Past challenges focused on the engineering process of MEMS, but future challenges will consist in adding embedded intelligence to MEMS systems, so that they will be able to collaborate efficiently. This will require embedding MEMS sensors/actuators, electronics, communication capabilities, control of actuators and programs in the same component which will be called later a unit.

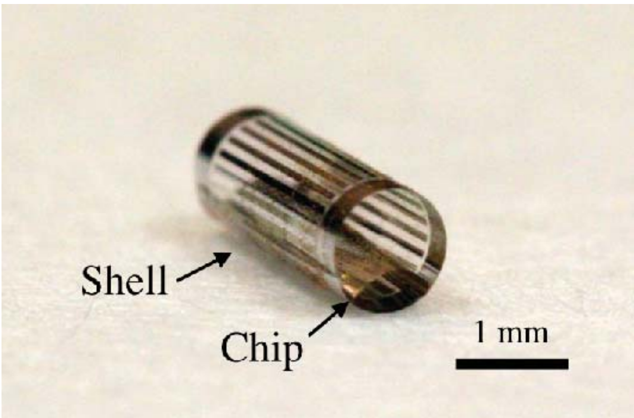
It is possible to add processing capacity linked to a distributed MEMS. It can be centralized on a PC or on an FPGA, but this limits the scalability of the system. Indeed, the central processing unit becomes a bottleneck, both in the hardware part with the wire scheduling but also in the software part with the management of communications and processing capability which raise bottleneck problems. A distributed architecture solves these problems. The use of the expression distributed intelligent MEMS has been suggested when referring to such an architecture.

Distributed intelligent MEMS systems[1] will be composed of thousands or even millions of systems which will raise new scientific challenges both for controlling and for programming such large ensembles. Scalability is therefore the main issue in this kind of new device. Distributed intelligent MEMS have the following characteristics: the need for synchronized actuation (local or global), the quality of the communication channel, the type of physical topology (mobile or static), and the type of logical topology (static or dynamic).
In FEMTO-ST, two projects have been initiated (Smart Surface[2] and Smart Blocks[3]) to study objects conveyance using distributed intelligent MEMS. Another project called "Coordination and computation in Distributed Intelligent MEMS (CO2Dim)"[4] studies the computer science part of DiMEMS system. More recently, a first study has been initiated on prognostic health management of MEMS. Finally, we are participating in the Claytronics project whose aim is to build programmable matter.

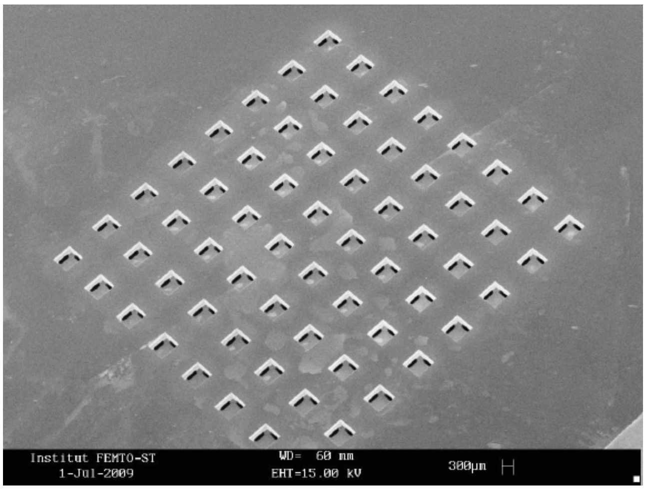
Contact
Julien Bourgeois: jbourgeo@femto-st.fr



Object sorting and conveyance with Smart Blocks



A Claytronics atom
(with the permission of Emre Karagozler, CMU)



A view on one prototype of Smart Surface

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Improved micro- and nano-structuring of lithium niobate

MIMENTO (Micro Nano Fabrication Facilities)

The development of nonlinear or electro-optical microresonators represents a stimulating challenge to achieve advanced functionalities in compact optical processing devices. An interesting approach consists of using high-reflectance Bragg gratings as building blocks for Fabry–Perot cavities. We have thus developed a set of techniques to etch giant aspect ratio nanostructures in lithium niobate. Actually, an 8 µm long Bragg grating on a Ti:LiNbO3 ridge waveguide was fabricated by combining optical-grade dicing and focused ion beam milling[1].

The first step consists in fabricating a planar waveguide on X-cut wafer by titanium indiffusion. Then, in order to confine the modes laterally, a ridge structure is etched by optical grade dicing with a circular precision saw (DISCO DAD 3350). The prepared ridge is 5.6 µm wide at its top and 48 µm deep. This method allows us to simultaneously cut and polish the lateral sides of the ridge. The high confinement achieved is fundamental to enhance electro-optical and nonlinear effects in the waveguide.
Finally, a Bragg grating with five air grooves is etched by FIB milling on the top of the ridge. This fabrication process offers the ability to etch indifferently from the topside or from the lateral side of the ridge. However, etching from the topside of the ridge ineluctably leads to conical-shaped patterns in the depth of the ridge, with sidewall angle no better than 8° due to matter redeposition during the etching process. This conical shape induces a major unwanted effect: transmitted and reflected light through the grating sinks into the substrate after a few periods only. However, if the pattern is milled from the lateral side of the ridge, the aspect ratio is just limited by the length of the lateral trenches. In the figure the grating shows a depth of 5 µm, but this depth can be easily increased by etching longer trenches along the sidewall. Now the trench sidewall angle is reduced from 8° to 3.8° as the FIB can go through the entire width of the ridge, which limits matter redeposition during etching. The Bragg grating was etched in less than 2 h with a probe current of 230 pA, a write field of 50 µm, a step size of 10 nm, and a dwell time of 0.1 ms.

This technological process gives the opportunity to fabricate gratings with quasi-parallel trenches together with giant aspect ratios improving performance. In this device, reflectivity reached 53% for TM polarization and 47% for TE polarization.

We may note that the strategy used here for etching high aspect ratio nano- and micro-structures on LiNbO3 can certainly be adapted to other hard-to-etch materials.

Contact

Nadège Courjal: nadege.courjal@femto-st.fr

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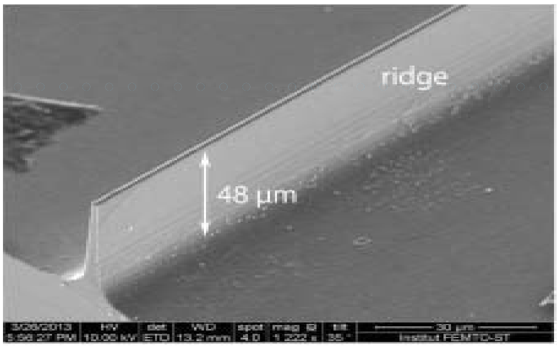
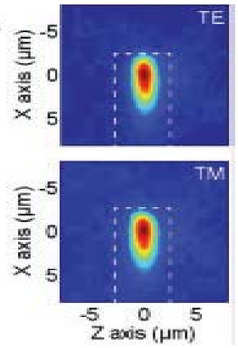
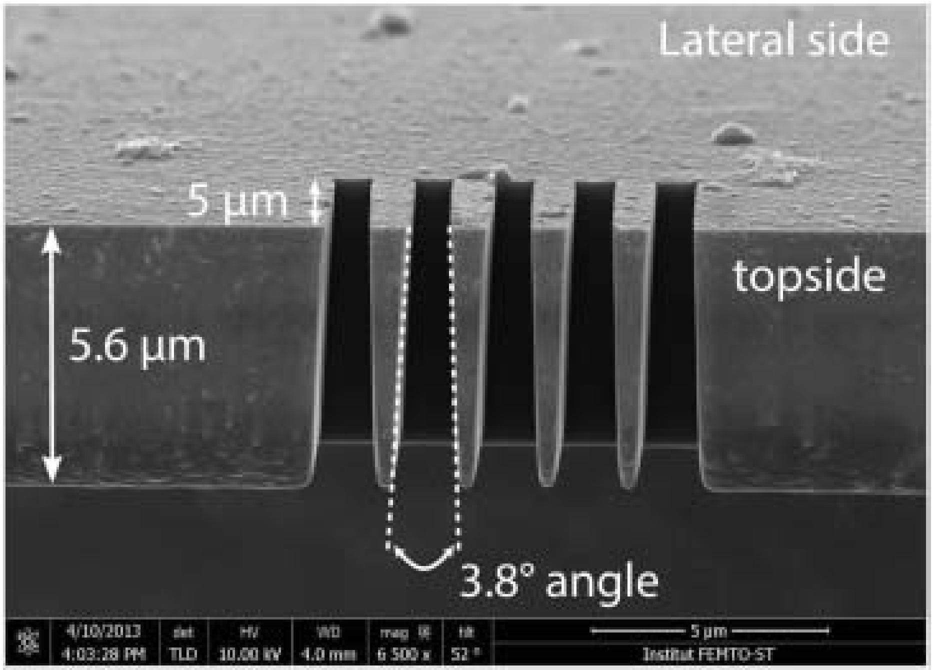


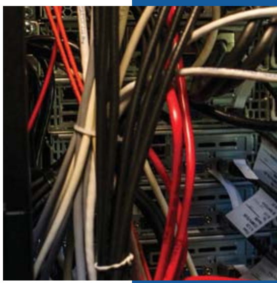
SEM image of a ridge made by optical grade dicing

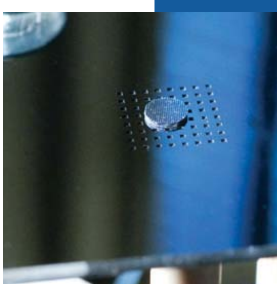


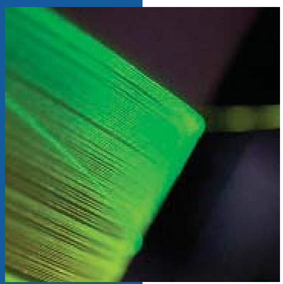
Visualization of TE and TM modes at 1.55 µm with IR camera. The dashed lines represent the limit between the ridge and the air.

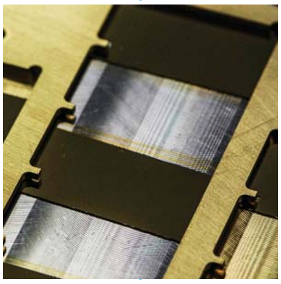


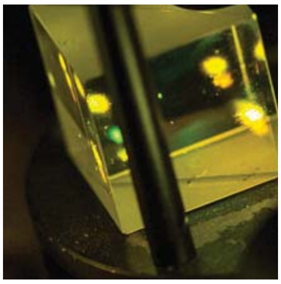
SEM view of the Bragg grating etched from the lateral side of a ridge by FIB milling. The tilted view allows to see the bottom part of the Bragg grating. The dashed lines show the sidewall angle.












SCIENCES & TECHNOLOGIES

FEMTO-ST Institute
32, avenue de l'Observatoire
25044 BESANÇON cedex
France

Tel.: +33 (0)3 81 85 39 99
Fax: +33 (0)3 81 85 39 68