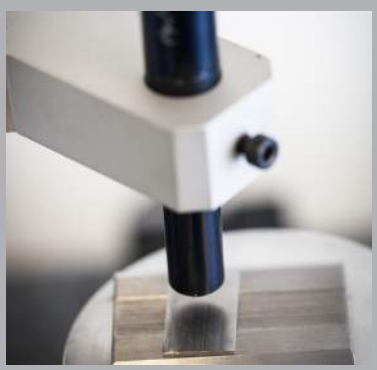
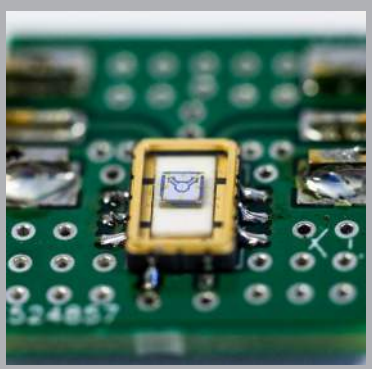
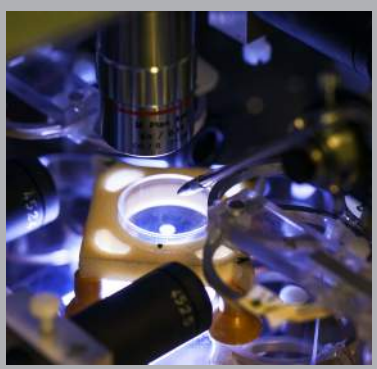
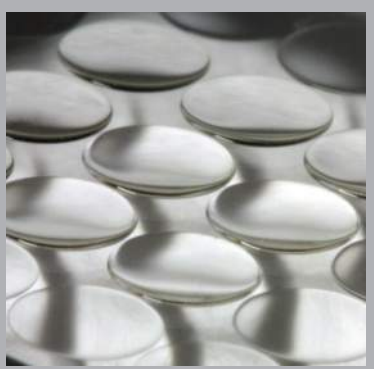
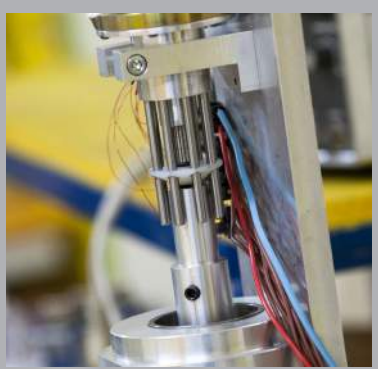
femto-st

SCIENCES & TECHNOLOGIES

2014 Annual Report

FEMTO-ST, a joint Research Institute from :

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Editorial

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 & Phononics, Computer Science, Energy, Applied Mechanics, Micromechatronics, Microsystems & Nanotechnologies, Optics & Photonics, Time & Frequency.

Our Institute was created in 2004 and thus celebrated this year its 10th anniversary. One very important event of the year was the move of more than 200 members of FEMTO-ST and their equipment and experimental setups to a new, dedicated research building in Besançon. It was hard work for some months and I would like to thank all of them.

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 and transfer activities, awards and publications in 2014. Its objective is to give a brief overview to the reader through a few selected focuses, which emphasize a selection of 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.

Beyond the move in a new building for 1/3 of the staff only, 2014 was more globally again a very active year for the whole FEMTO-ST institute. All our achievements would not have been possible without the constant involvement, professionalism and creativity of the whole staff. All these persons must again be praised for their dedication.

FEMTO-ST 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 and transfer, 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, the 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 impact 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
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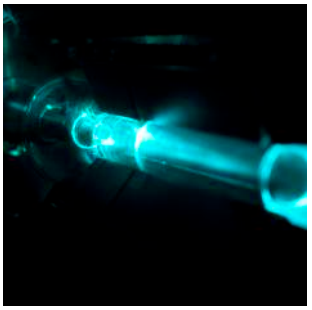
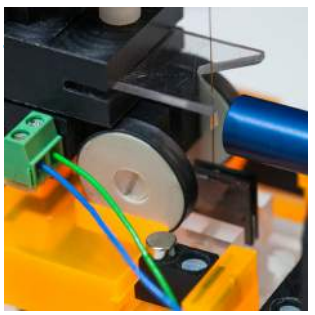
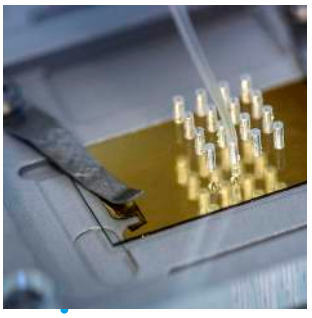
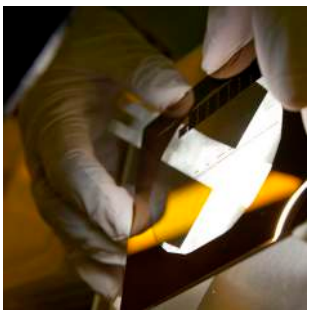
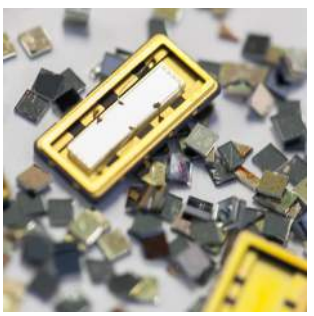










FEMTO-ST in figures...

The average staff count of the institute in 2014 amounts to roughly 700 people. This comprises the permanent staff members (professors, researchers, administrative and technical staff), as well as non-permanent staff members (doctoral and post-doctoral students, administrative and technical staff, students, guests, visitors).

The distribution of the staff members at FEMTO-ST in 2014 was:

- Permanent Researchers: includes assistant, associate, and full professors (UFC, ENSMM, UTBM) and full time junior and senior researchers (CNRS);

- Contractual Researchers: PhD students, postdocs, invited professors;

- Support for the Research: Administrative and Technical staff.

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

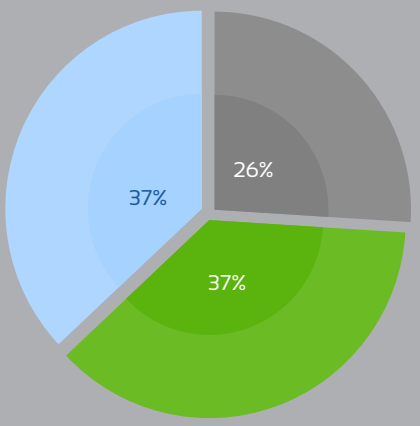
In 2014 the total budget of the Institute reached €14.3 million which can be broken down as follows:

- Annual funding from institutions (excluding calls for projects and doctoral contracts): 1.6 M€,
- Resources from contracts and research projects: €12.7 million.

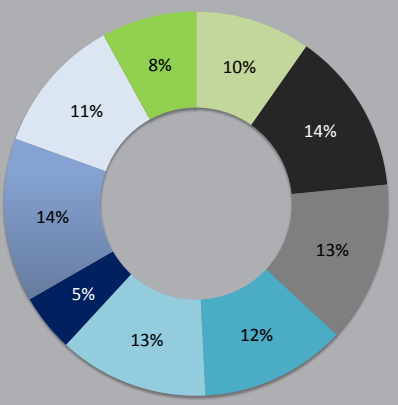
The detailed budget can be drawn up as follows:

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

Research FEMTO-ST



Budget FEMTO-ST



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Central Support Services and Quality Assurance

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 AFAQ 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 economic 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, Micro-analysis, Forming Processes, Vibrations & Acoustics, Scientific Computing as well as Engineering & Support Team.

At the beginning of 2014, AFNOR conducted a follow-up audit which confirmed the certification awarded one year earlier.

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A few flagship projects

PIA

Laboratory of Excellence (LabEx) ACTION

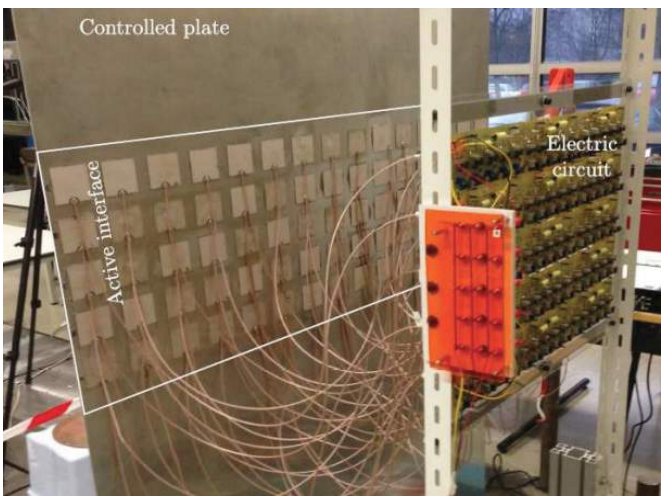
Towards smart matters and highly integrated smart structures

The Labex ACTION (ANR-11-LABX-0001-01) aims:

- To encourage ambitious scientific projects on an international scale and to increase its quality level including the recruitment of 2 chairs of excellence in 2014;
- To contribute to the development of innovative education programs that foster cross-pollination between research and engineering fields (4 Masters of engineering linked to the field of Smart systems have been supported by ACTION since 2013);
- To promote collaboration and transfer of knowledge towards the economic world, in cooperation with the SATT Grand Est.

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 for:

- 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.



A reconfigurable screen equipped with some distributed piezoelectric patches for vibration control and health monitoring.
© FEMTO-ST

ACTION key figures:

- Creation in 2012
- 3 research labs: FEMTO-ST, ICB Dijon, LNIO Troyes
- 5 technological facilities: MIMENTO Besançon, Quartz-Tech Besançon, ARCEN Dijon, NANO'MAT Troyes, PICASSO Dijon
- 5 associated labs: EPFL Lausanne, IRTES5 Montbéliard, Institut de Mathématiques de Bourgogne Dijon, Laboratoire de Mathématique de Besançon, LM2S6 Troyes,
- Budget: 48 M€ over 8 years

A scientific program that includes 5 demonstrator projects:

Integrated smart functionalities
- Detect
- Evaluate
- Predict
- Respond

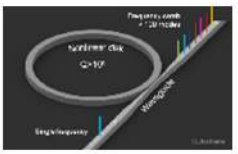
Requirements
- Specific materials
- Micro & Nanotech
- Computing & Control

DEMO 1 Adaptive metacomposites

Structural health monitoring, morphing...

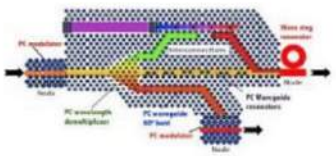
DEMO 2 Optical frequency comb generator

Optical signal processing (>320 Gb/s)



DEMO 3 Neuromorphic processor

High-complexity computations, Pattern recognition

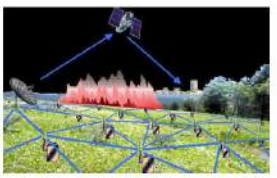


DEMO 4 Active spectral OCT endoscope

Precise, less invasive diagnosis & therapy

DEMO 5 Smart nanosensors

Reconfigurable, adaptive interrogation



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

Coordinated by Michel de Labachelerie, ACTION also benefits from the recommendations of a strategic board including 5 academic and industrial expert members:
- Prof. Hugo THIENPONT (President of the committee), Vrije Universiteit Brussel (Belgium);
- Dr. Sylvain ALLANO, PSA Peugeot Citroën (France);
- Dr. Jean CHAZELAS, THALES DMS (France);
- Dr. George AKHRAS, Royal Military College of Canada;
- Prof. Adrian IONESCU, EPFL (Switzerland).

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www.labex-action.fr

ANR · Franche-Comté Conseil régional · utt université de technologie · Grand Besançon · Pays de Montbéliard Agglomération · Ministère de l'Enseignement Supérieur et de la Recherche

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...

Cryogenic Saphir Oscillateur at the ESA Deep Space Antenna in Malargüe (Ar)

Silicon MEMS Resonator

Contact
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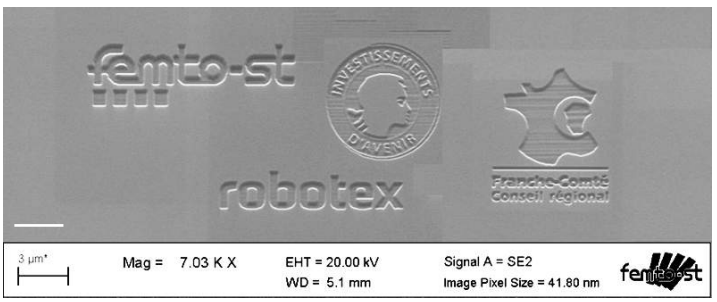
µROBOTEX Equipment of Excellence (EquipEx)

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.

µROBOTEX facility.

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.



Etching on silicon.

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http://equipex-robotex.fr/thematiques/micro-nano-robotique-microrob/
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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 "weighted" as precisely as a one-kilogram mass.

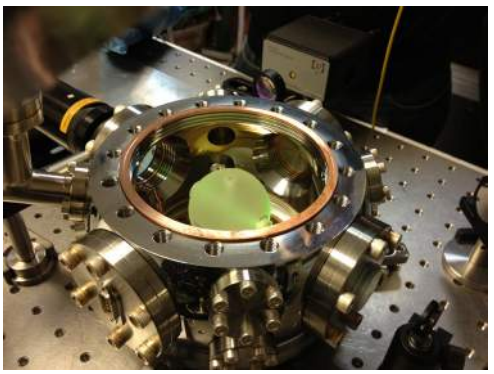
Scanning the technology, we notice that virtually all devices and systems rely on an oscillator stable for a suitably short measurement time τ. By contrast, the accuracy at long τ is provided by an external reference, and ultimately on primary atomic clocks. This pattern is found in radars, telecom, 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 sec. to 1 day) 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.

This ambitious project benefits from the high profile of our Time and Frequency Department. Through the LNE-LTFB, we are already affiliated to the LNE (Laboratoire National de Métrologie et d'essais) 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 (Bureau International des Poids et Mesures) for the measurement of frequency fluctuations. And the one and only laboratory listed by the BIPM for phase noise measurements.



Contact

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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

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

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

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**

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 test section from Villetaneuse (close to Paris) to Reims that the clock signal can be transmitted, throughout the Internet academic network RENATER over 540km, with a "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 course of its fluctuations.
This result paves the way to clock comparison on a conti¬nental 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.

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

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 in France. This is thanks to the Oscillator IMP Equipex, and also for physical experiments that require accurate and stable frequency at both ends of the fiber. 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+ aims to provide the highest absolute accuracy.

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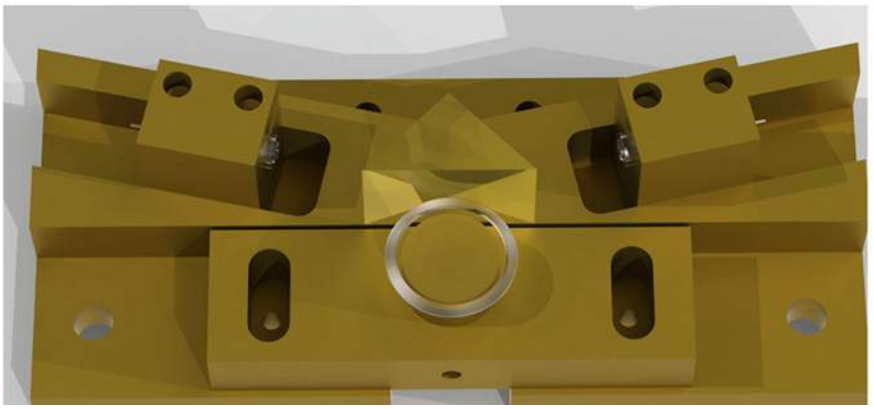
ERC

European Research Council
Established by the European Commission

ERC Proof of Concept VERSYT

(VERsatile, ultra-stable, multi-coherent and compact microwave photonics SYsTems)

Yanne K. CHEMBO
ERC NextPhase and LabEx ACTION



Schematic representation of a prism-coupled whispering-gallery mode resonator. This coupling configuration is particularly robust, but high-performance requires temperature stabilization, isolation from vibrations, and reliable connections.

Optical frequency combs are characterized by their exceptional spectral purity and their high coherence in the lightwave and microwave frequency ranges. They are therefore ideal candidates for coherent optical telecommunication systems, or for the generation of ultra-stable microwaves. It is today possible to generate these combs using monolithic nonlinear whispering gallery mode resonators pumped by a continuous-wave laser. These systems have the advantage of being simple and energy efficient. They are therefore becoming competitive compared to conventional sources.

The purpose of the ERC Proof of Concept VERSYT is twofold. Its first aim is to investigate robust resonator packaging solutions leading to system integration in volumes smaller than the one of a smartphone, and ideally, comparable to the size of a matchbox. The second objective is to investigate the industrial attractiveness of this kind of microwave photonics solutions.

In order to achieve these objectives, our research group at FEMTO-ST has teamed up with Crystal Device Technology (a FEMTO-ST spin-off) for the test and standardization tasks, and with INNEA – Expertise et Conseil en Innovation for the pre-industrial study.

Science & technology
femto-st SCIENCES & TECHNOLOGIES

Pre-industrial study
INNEA EXPERTISE & CONSEIL EN INNOVATION

Tests & standards
Crystal Device Technology

Contact

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ERC Proof of Concept WAVEMEASUREMENT

(Calibration of extreme wave measurement on the ocean surface)

John M. Dudley (Co-investigator with F. Dias, University College Dublin, Ireland)
ERC MULTIWAVE (2011-2016), ANR Optiroc and LabEx ACTION

The key idea of this Proof of Concept project is to implement rigorous performance and calibration tests of a new design of wave buoy in an extreme ocean environment in order to quantify the occurrence of high amplitude rogue waves. The project builds on the ERC Advanced Grant MULTIWAVE which has provided new insights into the fundamental mechanisms underlying the physics of rogue waves –large scale coherent structures emerging from a noisy or turbulent environment. The potential of the fundamental science in MULTIWAVE to improve the understanding of ocean rogue waves is enormous, but is hindered by the lack of reliability of measurements of extreme ocean waves. Put simply, both the quality of the data and the sophistication of data analysis of existing wave measurements from conventional buoy sensors are based on decades-old technologies and methodologies and are unsatisfactory for the detailed study of rogue waves.

Waverider buoy which will be adapted for WAVEMEASUREMENT project

The project WAVEMEASUREMENT is being implemented in collaboration with an Irish SME TechWorks Marine, a company specializing in ocean instrumentation. The idea is to combine our research on the physics of extreme waves with recent developments in buoy design in order to optimize buoy wave record measurement technology for waves of high amplitude and steepness. Commercial applications, if successful, would include marine renewable energies, shipping, marine forecasting, and ocean observation.

Science & technology

Deployment

Contact

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TEMIS Sciences

The management of the FEMTO-ST Institute and two scientific departments (Micro-Nano-Science and Systems – called MN2S - and Optics departments) settled in September 2014 in a new building named TEMIS SCIENCES. This building of 5300 m^2 area is located at the heart of the TEMIS technology park, including several start-ups and high tech companies. The building is also very close to the FEMTO-ST clean room facilities, called MIMENTO (865 m2), as well as ENSMM and University of Franche-Comté, where four other disciplinary departments of FEMTO-ST are already located (Applied Mechanics, Automatic Control and Robotics, Time-Frequency metrology and devices, Computer Science).

This building is dedicated to the Research, Education and Development in all scientific fields of excellence of the FEMTO-ST Institute, such as Photonics, Acoustics/Phononics, Micro and Nanotechnologies, Health and Biomedical applications, new photonic paradigms for sensing and information processing.

The researchers are now benefiting from 1150 m2 of laboratories with top-level infrastructures, enhancing progress in their scientific activities. By merging in a single place the MN2S and Optics departments, tighter interactions between researchers would emerge, strengthening and broadening an already successful interdisciplinary collaboration within the Institute. In addition, the building is open to other laboratories (e.g. medical sciences), so that they can also benefit from the physics and engineering expertise developed at FEMTO-ST. The economic transfer of the research results will also be strengthened thanks to the location in the TEMIS SCIENCES building of FEMTO Engineering, a business unit managing the development coming from the scientific and technological know-how of FEMTO-ST.

This new building will reinforce the position of the FEMTO-ST Institute as an international leader in Engineering Sciences and ICT. Beyond its modern architectural style with an admiral ship-like evocation, the building was also constructed according to the latest ecological and energy saving rules fixed by the European BBC HQE standards.

Contact

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FUI Projects
(Fond Unique Interministériel)

NEOTAG (2014-2017)

NEOTAG aims to develop and validate an analytical solution based on a multiplex format assay in the field of newborn screening test. The global idea is to combine biochip technology from FEMTO-ST with mass spectrometry (MS) approaches mastered by CLIPP and Immabiotech to perform simultaneous biomarker detection in blood. This program aims to respond to the recommendation of the French Health Council (HAS) for the global MS analysis of numerous metabolic disorders and diseases of newborns. Three pathologies will be especially targeted: congenital hypothyroidism, congenital adrenal hyperplasia and cystic fibrosis.

Partnership
Industrial partners: Immabiotech, R&D Biotech
Competitiveness clusters: Nutrition Health Longevity cluster & Microtechniques cluster

Fundings
Région de Franche Comté, CAGB, BPI France

References:

[1] K.Charriere, A. Rouleau; O. Gaiffe, J. Fertey; P. Morel, V. Bourcier; C. Pieralli, W. Boireau, L. Pazart, B. Wacogne, Biochip technology applied to an automated ABO compatibility test at the patient bedside. Sensors & Actuators B, 208, 67–74 (2015)

[2] Rouleau A., El Osta M., Lucchi G., Ducoroy P., Boireau W.,Immuno-MALDI-MS in Human Plasma and on-Chip Biomarker Characterizations at the Femtomole Level. Sensors 12, 15119-15132, (2012)

From blood collection from neonatal heel prick (Guthrie Test) to biochip technology and MS readout.

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DEQUALC

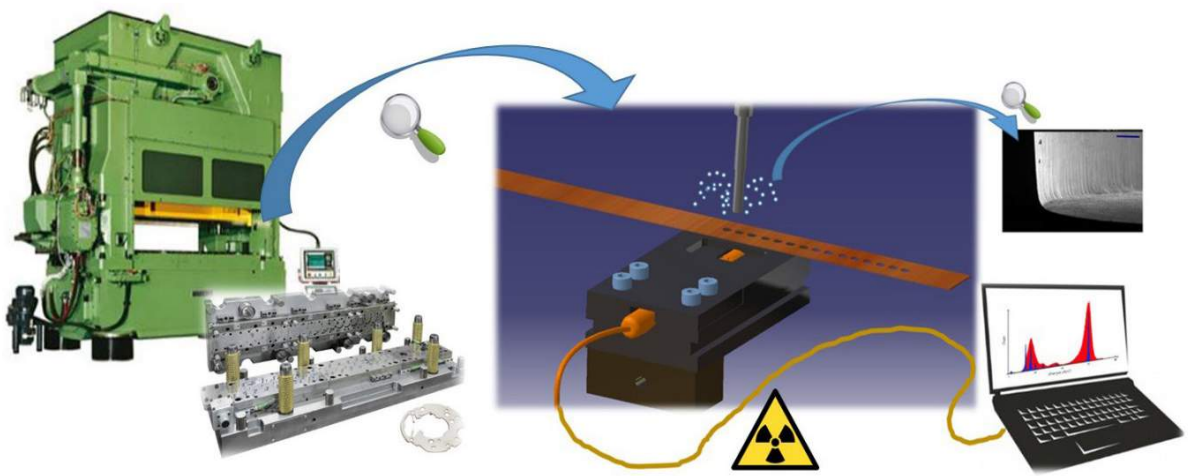
The objective of the FUI Dequalc project is to improve the quality of the parts produced by blanking (dimensional accuracy, height of the burr and aspect of the blanked edge). In order to achieve these goals it is necessary to identify the wear mechanisms of the blanking tools. The lifespan of the blanking tools is the key issue to improve quality of the product. In this project FEMTO-ST is in charge of developing methods for in situ and real-time measurement of the wear of the tools in industrial presses, developing laboratory tests to replicate wear mechanisms (abrasion, adhesion, pitting...) of the punches and developing computer codes for prediction of the tool behavior. The ultimate goal is to improve the quality of parts by improvements of the tool material, the blanked sheets and the blanking parameters.

Partnership
Industrial partners: Delphi, R. Bourgeois, Scoder, SoprecInterplex, Evatec Tools
Technical Centre : CTDecSavoie
Laboratories : CEMTHI CNRS Orléans, LICB Dijon.

Fundings
CG25, Région de Franche Comté, Europe, CAGB, Région de Bourgogne, FUI, CG21, CG74, Communauté Urbaine Le Creusot-Montceau les Mines

References:

[1] Numerical and experimental analyses of punch wear in the blanking of copper alloy thin sheet E. Falconnet, H. Makich, J. Chambert, G. Monteil, P. Picart, Wear 296 (2012) pp598–606



Thin layer activation measurement on the wear of a punch in an industrial blanking press

Contact
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Elastomere Silicone LSR

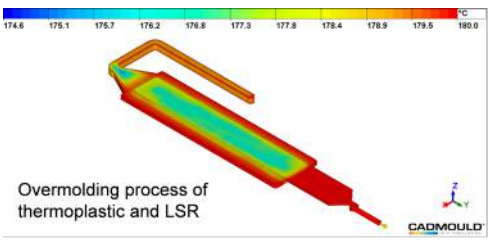
The objective of the FUI Elastomere Silicone LSR (liquid silicone rubber) project is to develop innovative components elaborated with thermoplastic and elastomeric LSR by the over-molding process and to create a large French partnership consortium. The Polymer and loaded polymer team of the Applied Mechanics department works on the characterization and the behavior identification of the mechanical and thermo-physical properties of thermoplastic, elastomeric LSR and over-molding components. Specific phenomena of adhesion and adherence have been studied. Different models dedicated to filling and vulcanization of the processed materials have been proposed. These models were implemented in the Cadflow software in order to propose efficient simulations of the over-molding process combining polymer thermoplastic and LSR elastomer. Validation and identification of the behavior laws have been realized through the experimental data collected in our lab. The models obtained were implemented into the software. Examples of the simulation have been achieved.

Partnership
Industrial partners: Bluestar Silicone, A. Raymond, Radiall, Cadflow, Tecmaplast, Spit, Grosfilley, FENEC SA, SDR, FENEC SA
Technical Centre : PEP Oyonnax
Laboratory : OPERP Nantes

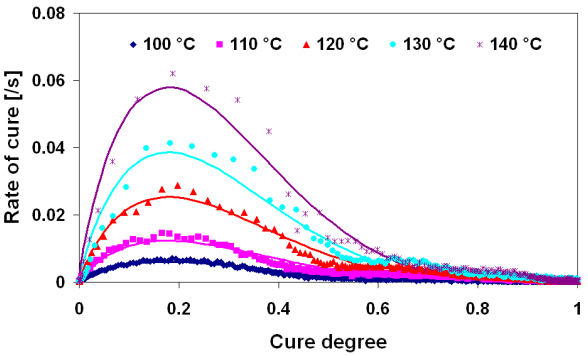
Fundings
CG25, Région de Franche Comté, Europe, CAGB, FUI, CG39

References:

[1] H. Ou, M. Sahli, T. Barriere and J.C. Gelin. Adhesion strength study of silicone rubber compounds to nylon 66, Key Engineering Materials, Trans Tech Publications, Switzerland, Vols. 622-623, (2014), pp 453-458.



3D Numerical simulation of over-molding process based on identification of the thermo-rheo-kinetics behaviors of thermoplastic and LSR elastomeric



Identification of vulcanisation stage

Identification of behavior and numerical simulation of over-molding process of thermoplastic and liquid silicone rubber elastomer

Contact

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ProPIM (2013-2015)

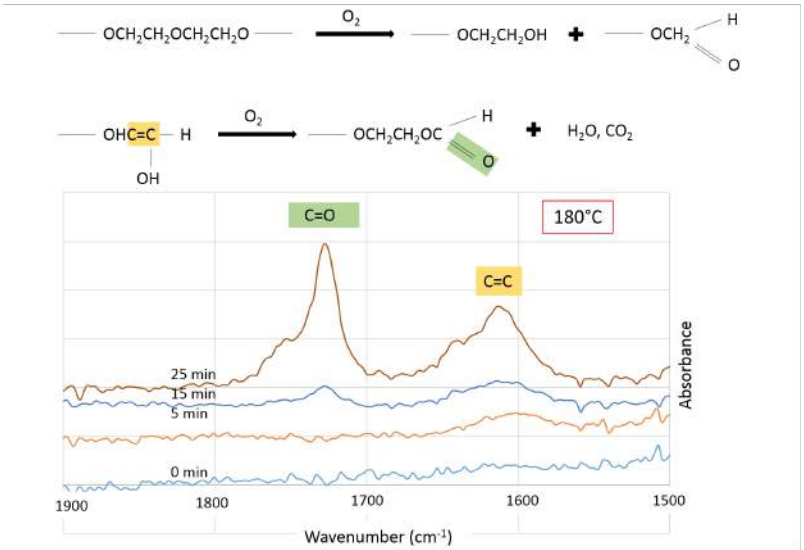
The objective of the FUI ProPIM project is to develop PIM micro components with superalloy powders. Accurate micro-components can be obtained in very large series for automotive and aeronautics connector applications. The Polymer and loaded polymer team of the Applied Mechanics Department at the FEMTO-ST institute works to understand the interactions between the powders and thermoplastic polymers. Specific studies have been realized with new RTIF infrared systems to quantify the interactions between binder and powders. Miscibility of different thermoplastic binders is studied. The innovative sintering processes for Inconel superalloy have been studied, for example micro-wave sintering and spark plasma sintering. Reduction of the sintering cycle and a better control of the grain size have been achieved.

Partnership
Industrials : A. Raymond, Radiall, P. Vuillermoz, Eurotungstene, Runispsys, Vp-Plast
Technical Centres : PEP Oyonnax, CEA

Fundings
CG25, Région de Franche Comté, Europe, FUI, CG39, Bpi France

References:

[1] A. Royer, J.-C. Gelin, T. Barriere, «Characterization by Infrared spectroscopy of binder based on polyethylene glycol and Inconel 718 feedstock for powder injection moulding», J of Computer Methods in Materials and Science, Vol. 15 (2015),1-6.



Schematic of the mechanism for PEG degradation and FTIR spectra of its evolution at 180°C, with the appearance of carbonyl group (green) and alkene group (yellow).

Contact

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ConProMI

The objective of the FUI ConProMi project is the development of a hybridization chain from different clean room and micro-mechanical processes with different functional polymers in order to obtain micro-components or components with very high surface structuring. Functional nano-composite polymers have been developed with different loads (CNT, powders ...) and a hybridization chain has been developed coupling silicon and elastomeric molds, hot embossing and powders processing processes. Several multi-physic models of amorphous polymers for micro hot embossing processes have been realized and compared with instrumented micro tools and the micro and nano polymer injection processes have been studied. The various structured parts obtained by an injection process on a silicon mold with a shape of 50 nm squared with different thermoplastic polymers have been obtained without injection molding defects such as short shot, air trap, warpage, ...

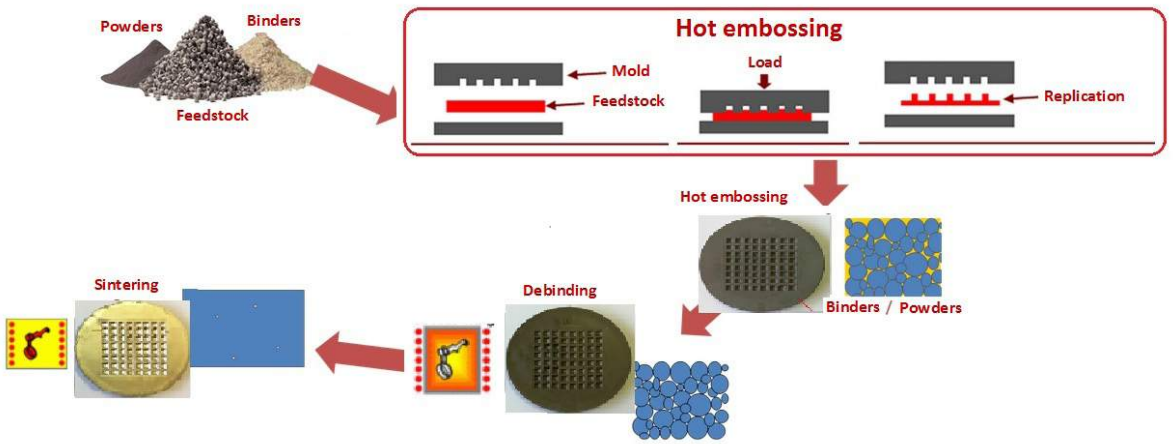
Partnership
Industrials : A. Raymond, Radiall, Cadflow, Vuillermoz SA, Cg-Tech injection, Isa France, Billion, Adapt plastic, MIP, ...
Technical Centres : PEP Oyonnax, CEA
Laboratories : IUT Chambery, INL Lyon

Fundings
CG25, Région de Franche Comté, Europe, CAGB, FUI, CG39, Bpi France, ...

References:

[1] G. Cheng, M. Sahli, J-C. Gelin, T. Barriere «Process parameter effects on dimensional accuracy of a hot embossing process for polymer-based micro-fluidic device manufacturing», International Journal of Advanced Manufacturing Technology. Vol. 75 (2014) 225-235.

[2] J. Zhang, M. Sahli, J-C. Gelin, C. Khan-Malek «Rapid-manufacturing of micro-structured devices based on MWCNTs/PP composites by using hot embossing replication process», Microsystem Technologies, Vol. 20 (2014) 1919-1924.



Development of a hybrid chain in order to elaborate micro-fluidic devices with loaded polymers coupled with hot embossing,

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RHYTA

RHYTA aims to produce a Hydrogen Storage Tank using metal hydrides without rare earth metals for stand-alone relay stations powered by renewable energy. In order to meet project requirements, all partners are implied in order to couple all existing and new components. In this project FEMTO-ST is in charge of the study of the thermal behavior of the metal hydrides as an H2 storage material. The improved understanding leads to an optimization of the tank in correlation with relay station environment.

Partnership
Industrials: CASSIDIAN (Powidian), MAHYTEC
Competitive pole: Pole Microtechnique

Fundings
Région de Franche Comté, FEDER, FUI

References:

[1] G. Gay, C. Lexcellent, D. Chapelle . Thermomechanics of a metal hydride tank. Continuum Mechanics and Thermodynamics (2014), DOI 10.1007/s00161-014-0356-7

[2] G. Gay, D. Chapelle, D. Perreux , F. Thiebaud, C. Lexcellent. Stockage d'hydrogène sous forme d'hydrures métalliques pour application au stockage d'énergie dans des stations relais autonomes. GDR ActHyF, Jan 2013, France. pp.1 - 5

Stand-alone relay station on Elancourt site ; MAHYTEC metal hydride tank

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Projet P-AIR

Particle – Atmospheric Intelligent Research

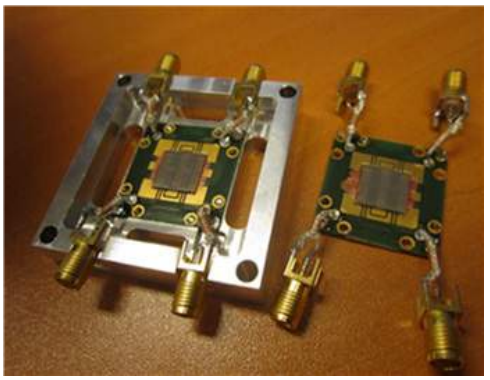
In response to the findings of the World Health Organization (WHO), which indicates that air pollution is responsible for approximately two million premature deaths per year, the Ministry of Ecology, Sustainable Development and Energy started in 2008 what is called the "particle plan". It consists in increasing the number of measures, in a variety of fields, aiming at reducing particle emission by up to 30% by 2015. This plan requires a huge scientific effort to improve the knowledge and the technologies related to the measurement and modeling of this type of pollution.

The P-AIR project, led by the company "TERA Environnement" and in partnership with Numtech, EcoLogicSense, ATMO PACA, the University of Provence and the University of Franche-Comté through the FEMTO-ST Institute, proposes to develop low cost particle sensors and to connect them through a dense network in downtown Aix-en-Provence, a leader city in the field.

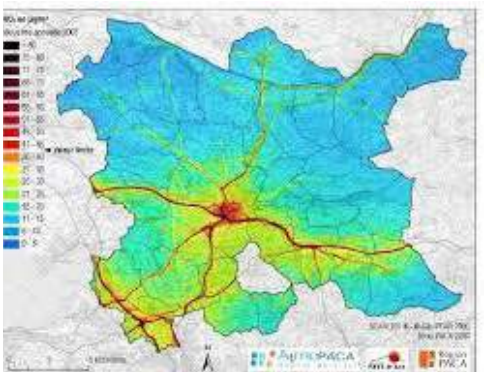
FEMTO-ST will take advantage of its recognized experience in the field of autonomous acoustic wave sensors, especially at the Time and Frequency department, to design and develop the sensors for this project. The gravimetric sensors will be manufactured at MIMENTO, the micro and nano technological center of FEMTO-ST, using clean room techniques.

P-AIR will yield a precise real-time mapping of particle pollution in the targeted area. In a foreseeable future, aided by a modeling system, it will be used for decision making. It will also permit to act in a preventive way by anticipating the periods of strong pollution and to put together smart actions so that particle emission sources would be efficiently reduced.

Duration : 3 years (January 2013 – January 2016)



SAW detection sensor



Mapping of particles displacement and prediction of pollution

Reference:

[1] D. Rabus et al. A high sensitivity open loop electronics for gravimetric acoustic wave-based sensors, IEEE Transactions, vol. 60, Issue 6 (2013) p. 1219-122

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Airpaca Observatoire Régional Qualité de l'Air

Laboratoire Chimie Environnement

ECOLOGICSENSE

NUMTECH L'ATMODÉLISATION

TERA environnement

Certified by the national competitivity clusters SCS, Risks & Microtechnics.

PÔLE RISQUES

SOLUTIONS COMMUNICANTES SÉCURISÉES

Inside everything Pôle des microtechniques

SCP Time Project

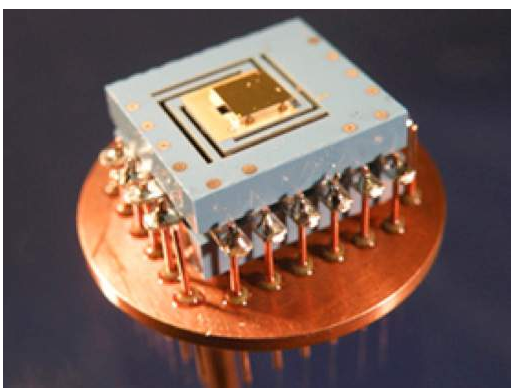
Since June 2014, the TF and MN2S Departments have been involved in an important project entitled SCP-Time, for Secure Certified Precision Time. This project has been selected for the ISI national program (Innovation Stratégique Industrielle), and is funded by the BPI (Banque Publique d'Investissement) for a global budget of a few million Euros. Within FEMTO-ST, the SCP-Time project is managed by Christophe Gorecki from the MN2S department.

SCP-time is a collaborative project led by Gorgy Timing, a major French provider of clocks and network synchronization systems for train stations or airports for example. The main partners of this project are Gorgy Timing, Eolas, SNCF, Minalogic, Syrlinks, µquans, Schneider Electric, and LNE, Observatoire de Paris, Osu theta (Observatoire de Besançon), FEMTO-ST.

The ambitious goal is to distribute a legal time, secured and fully traceable, essential in tomorrow's digital economy including communications, data transfers, localization, distribution networks, etc.

Two sub-projects have been defined so far. The first issue will consist in providing a secure, certified time-stamping and/or some secure certified time-stamping capabilities to the appropriate reference according to the target scope. Both Observatoire and LNE/FEMTO-ST are naturally involved through the maintenance and distribution of the French standard time as well as for the legality of its metrology.

The second issue deals with a kind of backup solution for time keeping. It could be provided by a local miniature atomic clock in case of the loss of the network link or GPS signal. FEMTO-ST and some of the industrial partners are in charge of this high-tech device. This local time base should not shift by more than one microsecond per day. Its volume should be less than 100 cm3 for a power consumption lower than 3W within [-10°C, +50°C]. Teams are working on a miniature CPT (Coherent Population Trapping) Cesium clock to meet these requirements.



Miniature Atomic Clock

Contact

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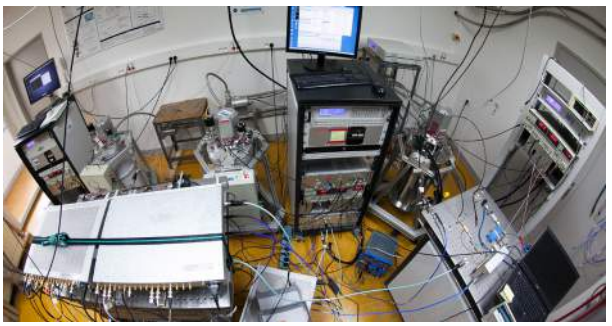
2008-2014, EU FEDER program

A long term European FEDER research program started in 2008 was successfully terminated in 2014. The important support of this FEDER program addressed many fields of research developed by the FEMTO-ST institute, allowing for several significant advances in Science and Technology, as well as contributing to many industrial transfers and to the creation of several start-up companies, all of this through the academic research supported by the FEDER program. The program contributed essentially to equip two R&D platforms in our institute with top-performance, high-tech equipment.
The first one is a platform for fabrication and characterization of components and micro components for terrestrial transports. The second one is dedicated to Micro & Nanotechnologies for Information and Communication Technologies and Biomedical Engineering.

The devices acquired with the support of the program are:

- Tools for hydroforming of tubes;
- A laminar flux gasket for manipulation of nanoparticles;
- An acoustic emission data acquisition for detection of fiber failures in composite materials;
- A high precision infrared camera for thermal measurements over micrometer square dimensions;
- an ultra-nano-indenter for ultra small mechanical characterization;
- A 'haptic' contactless temperature sensor to evaluate human-perceived temperatures;
- A MEMS (micro-electro-mechanical system) analyzer for the nano- micro-fabrication technology center MIMENTO;
- A ultra-high stability laser source locked on an ultra-low expansion optical cavity for time-frequency metrology;
- A femtosecond comb laser source bringing the technology of the new standard definition of time measurement;
- A cryo-generator providing record stabilization of a Sapphire microwave oscillator;
- An optical parametric oscillator dedicated to optical spectroscopic investigation and multi-photon imaging for nano- and micro-photonic device characterization;
- A Phazzler measurement system giving access to the accurate phase and amplitude characterization of ultra-short laser pulses of particular relevance in femtosecond laser machining;
- A heterodyne femtosecond scanning near-field optical microscope for the characterization of nano-photonic devices;
- A high performance and accurately controlled (temperature, humidity...) environment for micro-assembly station for micro-robotics investigations;
- A surface plasmon resonance instrumentation for the dynamic investigation of bio-interactions in living tissues;
- A micro- nano- fabrication and characterization station comprising a focused ion beam unit and a scanning electron microscope;
- And a state-of-the-art real time digital oscilloscope for advanced studies in microwave and photonic application for nonlinear dynamics, quantum, and brain-inspired information processing.

Over this 6-year period of the FEDER program, all these devices strategically contributed to several industrial developments and partnerships and also a set of patents. The projects involving these devices have been directly linked to more than 20 people recruited in high-tech start-up companies, 12 permanent positions at FEMTO-ST, and more than 60 contractual researchers (PhD and postdocs).



Cryogenic oscillator

Femtosecond OPO

Contact

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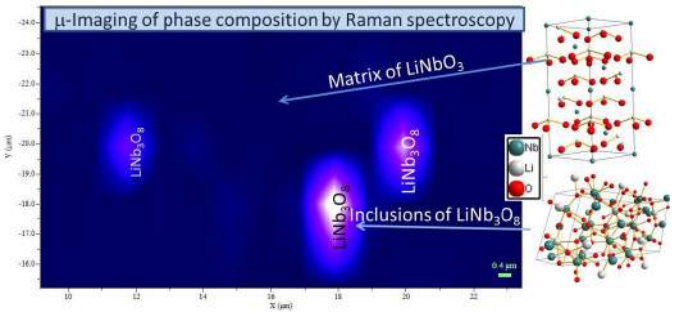
2014 Highlights

Chairs of excellence

Ausrine Bartasyte

The development of new technologies at the nano-scale requires for future micro-, nano-devices to tailor at the origin a) the material's functionalities and properties, and b) the suitable fabrication and processing strategy for low-cost, large scale implementation of advanced materials into devices in a cost-effective and reliable manner. $LiNbO_3$ (LN) single crystals are highly used for piezoelectric, pyroelectric, acousto-optic, electro-optic, and non-linear optical devices. Thin films of LN with high electro-mechanical and electro-optical couplings are thus highly desirable for integrated and miniaturized MEMS (micro-electro-mechanical systems), optical and acoustic (SAW -surface acoustic waves-, BAW -bulk acoustic waves-, HBAR -high-overtone bulk acoustic resonator-, FBAR -film bulk acoustic resonator-) devices. Indeed, the integration of such LN thin films into miniaturized devices would significantly increase the efficiencies of signal transmission, sensing and/or energy conversion. However, thin films and heterostructures of this material are not fabricated industrially due to the poor quality and hence limited functionalities that can currently be obtained. Thus, innovative methods compatible with Si technology and with up-scaling possibility for synthesis of LN films and heterostructures with suitable physical/chemical properties will be developed in the frame of Labex ACTION. A combined, integrated approach of synthesis and characterization, together with a modelling, theory and fabrication of devices, will be applied during A. Bartasyte's Chair of Excellence to lead to custom-made materials synthesized by an up-scalable process and viable for optical, acoustical, phononic and MEMS applications. This in particular concerns the deposition of single crystalline quality, single-domain, twin– and crack-free LN films with controlled crystallographic orientation on substrates/heterostructures compatible with current industrial technologies or offering direct integration to Si technologies.



2D mapping of $LiNbO_3$ and $LiNb_3O_8$ phase distribution on the surface of the film by means of Raman spectroscopy.

A. Bartasyte has an experience of 14 years in deposition of epitaxial multifunctional oxides and their heterostructures (superconductors, mixed conductors, high-k dielectrics and ferroelectrics) by means of PI MOCVD and RF sputtering. She started to work on thin films during her undergraduate studies in Chemistry at Vilnius University in Lithuania and PhD in Grenoble INP (2007). She did her postdoctoral research at Oxford University, on $LiNbO_3$, $LiTaO_3$ and $LiNb_{1-x}Ta_xO_3$ single crystal growth, study of their structure and the estimation/control of Li stoichiometry in $LiTaO_3$ crystals by VTE. At University of Lorraine, her research was focused on strain and chemical engineering of $Li(K)Nb(Ta)O_3$ thin films and single crystals for SAW applications. During her sabbatical leave to Harvard University, she optimized titanium oxide films for photonic applications. She has an excellent knowledge of $LiNbO_3$-$LiTaO_3$ family materials and their properties.

[1] A. Bartasyte, V. Plausinaitiene, A. Abrutis, T. Murauskas, P. Boulet, S. Margueron, J. Gleize, S. Robert, V. Kubilius, and Z. Saltyte "Residual stress and clamped thermal expansion in LiNbO3 and LiTaO3 thin films" Appl. Phys. Lett., 101, 122902 (2012).

[2] A. Bartasyte, V. Plausinaitiene, A. Abrutis, S. Stanionyte, S. H. Margueron, P. Boulet, T. Kobata, Y. Uesu, and J. Gleize "Identification of LiNbO3, LiNb3O8 and Li3NbO4 phases in thin films synthesized with different deposition techniques by means of XRD and Raman spectroscopy" J. Phys. Condens. Matter 25, 205901 (2013).

[3] A. Bartasyte, V. Plausinaitiene, A. Abrutis, S. Stanionyte, S. Margueron, V. Kubilius, P. Boulet, S. Huband, P.A. Thomas "Thickness dependent stresses and thermal expansion of epitaxial LiNbO3 thin films on C-sapphire" Mat. Chem. Phys. 149-150, 622-631 (2015).

Contact

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Chairs of excellence

Nadia Yousfi Steiner

Fuel Cells are complex systems where several physical phenomena (electrical, fluidic, thermic, electrochemical,..) occur at different scales. To ensure efficient, safe and reliable operation with competitive lifetime span, the Fuel cell system should be maintained in a narrow range of operating conditions. Many faulty operation modes result in performance loss, system shutdown or even irreversible failure. Therefore, methods that allow increasing tolerance to faults and thus increasing reliability and lifetime are highly needed.

The idea of controlling a system that deviates from its nominal operation has been largely investigated, first through the understanding of the deviation causes and mechanisms, then by developing tools that allow operating system's health monitoring and, as recently proposed, more recently by developing tools that are able to predict the future behavior and the remaining useful lifetime. The final aim of all these steps is to control the system in an optimal way, which includes integration of different aspects: predictive control, adaptive control and tolerance to faults.
Before designing a control that is tolerant to faults, many other approaches should be considered: faults comprehension, health monitoring and prognostics.
The used approaches are based on signal processing, non-intrusive, parsimonious towards sensing and easy to integrate online and onboard of an operating system, and matching the constrains of automotive and stationary applications.
The fuel cell system is seen as a smart system that monitors, analyses and sends information about its state of operation and adapts its control to the occurring faults.
The holder of this project is Nadia Yousfi Steiner, who joined the Labex ACTION on the 15th of September 2014, as chair of excellence assigned to the IUT-BM for the teaching part and FEMTO-ST/ENERGY department/SHPAC team for the research part.
She worked 7 years as researcher and R&D project manager at the European Institute for Energy Research in Karlsruhe (Germany) in charge of different project linked to fuel cells and hydrogen (as contributor, leader or investigator).

With competencies in diagnostics and prognostics of Fuel Cells systems, Nadia will contribute to the development of projects in the Labex Action through the Work Package WP5 entitled: «Modeling, System architecture, Information processing» and in the demonstrator DEMO3: «Neuromorphic processor».

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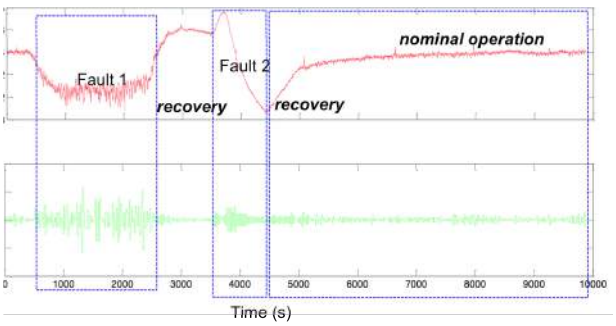

Evolution of voltage of an operating fuel cell, wavelet-based analysis of faults linked to water management (fault 1 & 2)

Contact

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AIM, a major international conference hosted by FEMTO-ST

The «Advanced Intelligent Mechatronics» Conference (AIM) is a conference co-sponsored by the IEEE and ASME societies, dealing with scientific results at the international level in automation, robotics and mechatronics. The conference has been co-organized in Besançon by the FEMTO-ST institute and the «Société Française des Microtechniques et de Chronométrie» (SFMC).

This annual conference is organized sequentially in US, Asia-Oceania and Europe. It consists in one of the most important international conference in advanced mechatronics. After Budapest, Hongria (2011), Taiwan (2012) and Wollongong, Australia (2013), the conference was organized for the first time in France, in Besançon in July 2014.

The conference started with workshops and tutorials focusing on challenging topics in the field of mechatronics. During the three next days, 308 speakers selected by the peer-review process presented their work in 20-minute talks in 6 parallel sessions. Four plenary speakers were invited by the Program Committee: Prof. John Dudley, Université de Franche-Comté, Takao Asami, Senior Vice president of Nissan Motor and Renault SAS, Prof. Jan Peters, Max Planck Institute and Prof. Reza Moheimani, University of Newcastle, Australia. Industrial tours and lab tours were organized during the last day. This French edition was characterized by record participation gathering up to 330 participants.

The organization of the international conference in mechatronics has reinforced the position of FEMTO-ST in the international community. This event was also the opportunity to promote micromechatronics as a field of expertise of the FEMTO-ST institute combining mechatronics and microtechniques.

AIM2014 Besançon FRANCE
IEEE/ASME International Conference on Advanced Intelligent Mechatronics

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CETSIS 2014 symposium

(Colloque Enseignement des Technologies et des Sciences de l'Information et des Systèmes)

The EEA Club, society of teachers and professors in Engineering Sciences, is the initiator of CETSIS. The French Physics (SFP), French Optical (SFO) and French Mechanical (AFM) societies are also partners of this event. The evolution of science teaching practices in higher education institutions is the essential purpose of CETSIS since 1997. Besançon, through the ENSMM, the University of Franche-Comté and UTBM, was chosen to organize the 11th edition of CETSIS from October 27 to 29, 2014. This edition of CETSIS resolutely turned towards the interdisciplinary.
This conference is THE primary forum of University, engineering schools, high schools, with regard to the evolution of teaching practices. It is interested in the diffusion of knowledge for a wide audience. It is open to the entire international francophone community. It is an important moment of pedagogy. It is a meeting between 100 and 150 colleagues talking about real manipulations, exchanging experiences on new pedagogies and technologies.

The CETSIS symposium was characterized by 4 sessions of poster presentations and demonstrations by the attendees. The CETSIS is original in that it favors Posters, Models, Equipment, and Demonstrations. The symposium is centered on demonstrations and tutorials. The major scientific themes are the engineering sciences, particularly Automatic Control, Electronics, Electricity, Microtechnology, Optics, Physics, Mechanics, Materials and Computer.

Magnetic levitation experiment

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

Beside 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 22 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).
The first two CMIs concerned by the research activities at FEMTO-ST, named PICS and S^3, 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, the institute has decided to push further this educational strategy in 2014, with the creation of two additional CMIs. One is centered around the field of Energy (H3E), and the other addresses Computer Science.

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Master Degree of Engineering Hydrogen-Energy and Energy Efficiency (H3E)

Based on a strong scientific background and large know-how in electrical and thermal engineering, the new CMI H3E (M.Eng. in Hydrogen-Energy and Energy Efficiency) aims at educating expert engineers in energy flow optimization and energy efficiency in different application areas: transport (road, railroad, aeronautical) or stationary applications (centralized energy production, insolated energy production, buildings). Beyond the conventional energy-related aspects, a focus on hydrogen-energy, the future archetypal energy vector, is also brought.
This new M. Eng. curriculum, supported by the STGI UFR (Univ. Franche-Comte) is directly related to the Energy Department of FEMTO-ST and to the Research Federation FCLAB. It offers a unique opportunity, through specific courses and in-lab training periods, for students to get familiar with the latest developments in research in the related areas.

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Master Degree of Engineering Computer Science

The new CMI Informatique (M. Eng. in Computer Science) aims at educating expert software engineers, and proposes two specialties in advanced techniques for software development, "software and network engineering", and "smart distributed systems". It focuses on software development processes through programming, modeling, computing theory, networks, security, web and mobile applications, software engineering (verification and validation).
This new M. Eng. curriculum is supported by UFR ST and UFR STGI (Univ. Franche-Comte) and is directly related to the research activities conducted at the Department of Computer Science for Complex Systems of the FEMTO-ST Institute. It offers a unique opportunity, through specific courses and in-lab training periods, for students to get familiar with the latest developments in research on the related areas.

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AUREA Technology

International Innovation Award for a spin-off

The winner: A source of quantum entangled twin photons

The importance of improving knowledge transfer between public research institutions and industry was identified by the European Commission as one of ten key areas for action. Following knowledge transfer strategy based on subsidized research joint ventures between FEMTO-ST Institute and Aurea Technology, a self-contained high-brightness Entangled Photon Pair Source at telecommunications wavelength, based on spontaneous parametric down conversion in Periodically Poled waveguide (allowing for Quasi phase Matching), has been developed.

This joint venture was initiated in 2012 through the recruitment by AUREA Technology of J.-M. Merolla, CNRS senior scientist at FEMTO-ST, as part-time scientific expert on single photon manipulation and quantum information theory [1]. This cooperation was developed through a FEDER project, SAPHIR, dedicated to innovation and high-tech transfer from the lab to the industry. This project aimed to develop a new generation of integrated high speed 1550 nm photon counter module for advanced biophotonic applications. Within this project, a compact correlated (entangled) photon pair source was implemented to provide an absolute way to calibrate the single photon counter module detection efficiency.

The company exhibited this device at the famous international Conference on Lasers and Electro-Optics (CLEO) 2014, which took place on 8-13 June in San Jose, California, USA. The AUREA product won the "Honorable Mention" for the 2014 Innovation Award from CLEO/ Laser Focus World. The sources of entangled photon pairs are indeed key devices for the study of quantum physics foundations as explored in the academia, but they are also of the highest interest in several emerging applications such as quantum information processing, quantum communication, and quantum metrology for bio-medical applications.

Aurea technology's first targeted market segments include the Research market for quantum information and quantum metrology, as well as the Education market. Beyond the highly constructive commercial impact for AUREA Technology, the licensing fees will also support the fundamental research activities of J.-M. Merolla at FEMTO-ST on quantum information theory in the optical frequency domain, a topic which precisely stimulated the development of the entanglement source. Such a collaboration is an exemplary interaction of how fundamental research activities can lead in the short term to the successful developments of innovative high-tech commercial products.

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FEMTO Engineering setting-up

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

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

Furthermore, FEMTO Engineering 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 considering 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.

In 2014 FEMTO Engineering added new activities and continued its recruitment campaign launched in 2013, bringing the staff up to 9 persons.

- Direction, Business Development, Administration and Communication : 2 persons;
- Technology Development: 7 persons are working for industrial companies and academics.

Energy:
- Modeling Engineer for electromagnetism and thermal, within FEMTO-ST MACH Team;
- Management of electrical energy for embedded and stationary systems (Hybrid & Fuel Cell Systems Research Team).

Optics:
- Femtosecond Laser Micromachining (OPTO Team).

Time & Frequency:
- ULISS, ultra-stable cryogenic oscillator, and Time & Frequency specific electronic developments;

Microfabrication using MIMENTO clean room facilities:
- On demand projects using coating, etching, lithography, characterization;
- RACE3 project with FEMTO-ST and Labex Action : developments of electro-optic, piezoelectric, ferroelectric single-crystal thin films;
- Biomedical activities : chips for SPR (Surface Plasmon Resonance) and bio analysis (the MIMU team).

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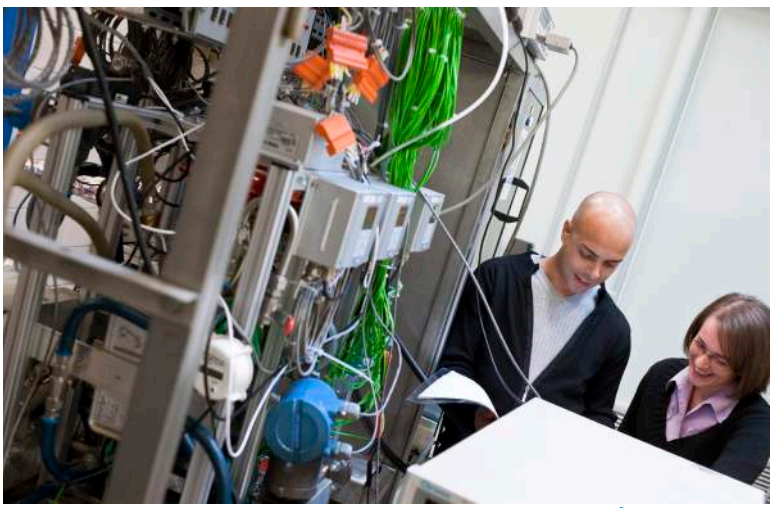

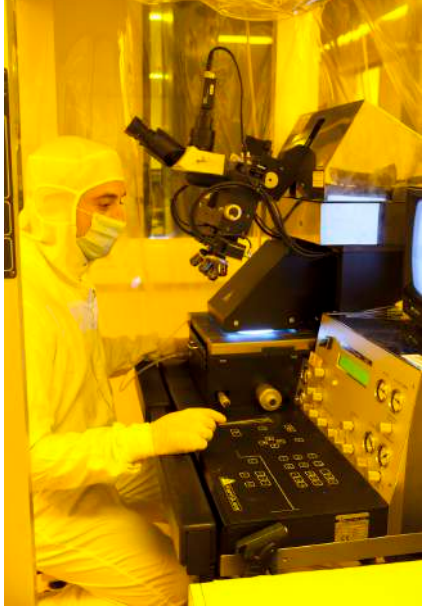

Focus on Spin-Offs

Photline

Photline Technologies is a spin-off of the Department of Optics of FEMTO-ST. Photline was created in September 2000 by three full time researchers of the optoelectronic group: Jerome Hauden, Pascal Mollier (MCF, UFC) and Henri Porte (DR, CNRS). In the context of a growing optical fiber communications market, Photline technologies received the support of investors and industrial partners, and of CNRS and of the University for its development. The transfer of technology aimed originally at launching a new generation of high-speed optical modulators. Thanks to fruitful developments in the fiber sensor domains, Photline found new markets outside of telecom, in particular in the inertial navigation system applications. Its portfolio of products extended to microwave driver amplifiers for modulators (50Gb/s). This was obtained after merger with the small company AdLightec in 2008, formerly based in Lannion. Mastering also modulator bias control electronics, Photline was able to launch a new family of products with advanced modulation instruments called ModBox.
Hosted during the first years in the facilities of the University of Franche-Comté, Photline moved in 2006 in a 1000m² industrial building in Besançon, where a clean room and a production line were organized. In 2013, Photline joined the iXBlue group. Photline realized at this time 6MEuros in sales with 40 people in more than 40 countries. In 2014, Photline won major contracts for space applications, with NASA and TESAT in particular. More recently, Photline signed a large contract to supply the Lithuanian laser manufacturer EKSPLA with pulsed modulated laser sources to be integrated in high power and intense laser channels in the mid-infra-red region. Since January 1, 2015, Photline has definitely become a part of iXBlue where it forms the Photonic Solutions business unit with the former company iXFiber based in Lannion. iXFiber is specialized in specialty fiber manufacturing and passive components (Fiber Bragg gratings mirrors and filters). The whole iXBlue group represents today more than 550 people doing sales for 100MEuros. iXBlue focuses on innovation and technologies and spends more than 20% of its budget for R&D. iXBlue is based on several industrial sites in France (Marly le Roi, Lannion, Brest, Bonneuil, La Ciotat and Besançon), and produces inertial navigation units and systems based on the fiber optic gyroscope (FOG) technology. iXBlue produces also acoustic positioning systems, sonars and photonics products. iXBlue is present in the off-shore market, civil and defense naval applications, space, lasers, and sensors.
The fast growth of its activities, in optics industry in particular, requires iXBlue Photonic Besançon (ex-Photline) to move out of its current facilities. This will be completed in august 2015, when the new building under construction and located in TEMIS in Besançon, close to the FEMTO-ST laboratory, will be achieved. The activity will then be deployed on two levels adding up to 2500m², with a large ISO6 clean room, and many clean spaces for assembly and testing laboratories.

PHOTLINE
AN IXBLUE BRAND

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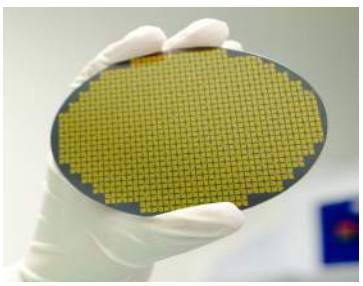
FREC'N'SYS

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 a half year growth in the Innovative Company Incubator of Franche-Comté, frec'n'sys (contraction of 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. The startup is now composed of 7 team members and 2 CNRS consultants, covering all the short-term needs of the company (Production, R&D, Computer Resources and Business).

The company is exploiting technological equipment for the fabrication of surface acoustic wave (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 and several characterization set-ups. This technology allows frec'n'sys to manage prototyping and small series fabrication, and the company ambitions to acquire more experience for producing larger series.

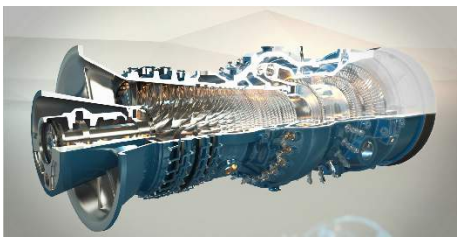


4- inch wafer

In that context, the company develops new competences in the field of MEMS, particularly for the fabrication of composite materials combining piezoelectric thinned wafers bounded to any single crystal wafer. This activity is developed in close collaboration with FEMTO-ST. The company benefits from 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 allow to address almost any wave guide configuration. frec'n'sys also 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 (750°C demonstrated) for which a new solution for sensor/antenna assembly has been developed and protected.

SafeMetal foundry



Gas Turbine

Areas of Activity

3 Core Business Activities
- Telecommunications: consulting, development of SAW components such as filters;
- Defence, aerospace, aeronautics: global offer for high quality passive RF components for embedded signal processing;
- Industrial automation, industrial manufacturing: saw sensor working under harsh environment (temperature, pressure...).

Technologies
- Microsystems and components design;
- Advanced materials, nanomaterials, smart materials;
- Micro and nanomanufacturing processes;
- Surface treatment, coatings, functionalization of surfaces;
- Smart systems, Micro and nanosystems (sensors, actuators,...), complex systems, nomadic devices;
- Micromechatronics technologies (micromechanics, opto-electronics, electronics, automation).

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Success Stories

Disciplinary Research

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

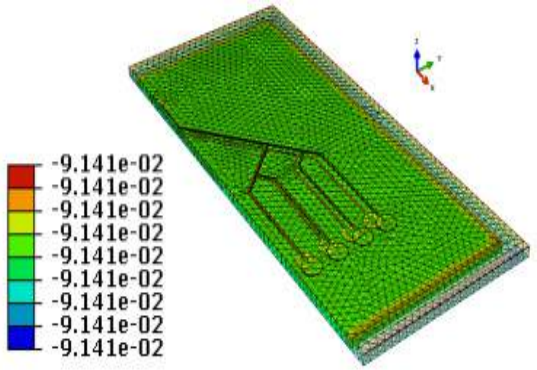
Applied Mechanics

For several years, and especially in 2014, the research activities in PLP (Polymers and Loaded Polymers) has achieved very important advances, with the finalization of ongoing projects and the development of new ones. These developments included in particular the FUI program NewPIM and the ProPIM projects. These projects focused on injection molding of metallic powders. Since they were successfully finalized, they resulted in the launching of new research activities in ProPIM, concerning different powders for additional charges in the feedstock mixture in order to obtain new functional materials. This specific research has been realized with bio-degradable and bio-sourced polymers.
Moreover, new partnerships have been developed with the large scale European company Erasteel, which enables us to investigate magneto caloric powders. These developments should lead to new applications in the field of magnetocaloric components, especially in the fields of micro and nanotechnologies.

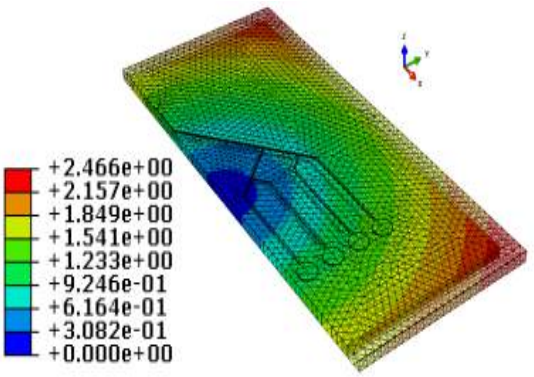
Furthermore, extensive work on carbon nanotubes and nano-particles has been carried out in the context of the design and manufacture of aeronautic components. Two Ph.D. theses have been launched on related subjects. One thesis focuses on the reinforcement and functional properties of the complex parts of aeronautic components. Another thesis is directed towards the development of blends for functional materials.

Thanks to our recognized expertise, our group became a partner for Mim Netshape of the CORAC DGA project hosted by SNECMA and SAFRAN Companies. This project focuses on the realization of super alloy components. Our PLP group is in charge of the elaboration of different MIM feedstocks for functional materials. This includes the mechanical and thermo-physical characterization of materials and components. New rheological models have been proposed and identified by experiments.

We have also developed new approaches for the manufacture of micro-components by hot embossing of polymers and filled polymers in the frame of the FUI program (ConProMI and Silicone LSR, see the section on FUI projects). A new concept with flexible molds based on a silicon wafer substrate, for rapid prototyping of microfluidic inserts, has been developed in the PLP group. These flexible molds provide a way to manufacture other metallic molds by PIM process. The final metallic molds allow microfluidic or nano-fluidic flows for the manufacture of micro component.
From December 2013 to June 2014, 5 PhD Students from our group (K. Metwally, J. Zhang, G. Cheng, B. Mamen and H. Djoudi) defended their theses. Two additional co-supervised PhD theses (J. Hidalgo and J. Shi) were defended in 2014, in cooperation with the Charles III University of Madrid (Spain), and SWJT University (China). The PLP group has a long history of research collaboration with SWJTU with 4 co-supervized PhDs.



Estimation of final density



Estimation of final shrinkage

Simulation of sintering stage for the molded components made by flexible substrates.

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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 constitutes 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" at the industrial trade-show 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 at the 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.

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

AS2M (Automatic Control, µ-Robotics and Prognostics)

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 (top figures). This work, done in collaboration with UMI 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.

This work was done in collaboration with the Interactive Robotics Laboratory of the CEA LIST, France. The bottom figures are examples 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 a hysteresis compensation controller. This multidisciplinary mechatronic design approach gives integration and performance rates far beyond those found in the literature.

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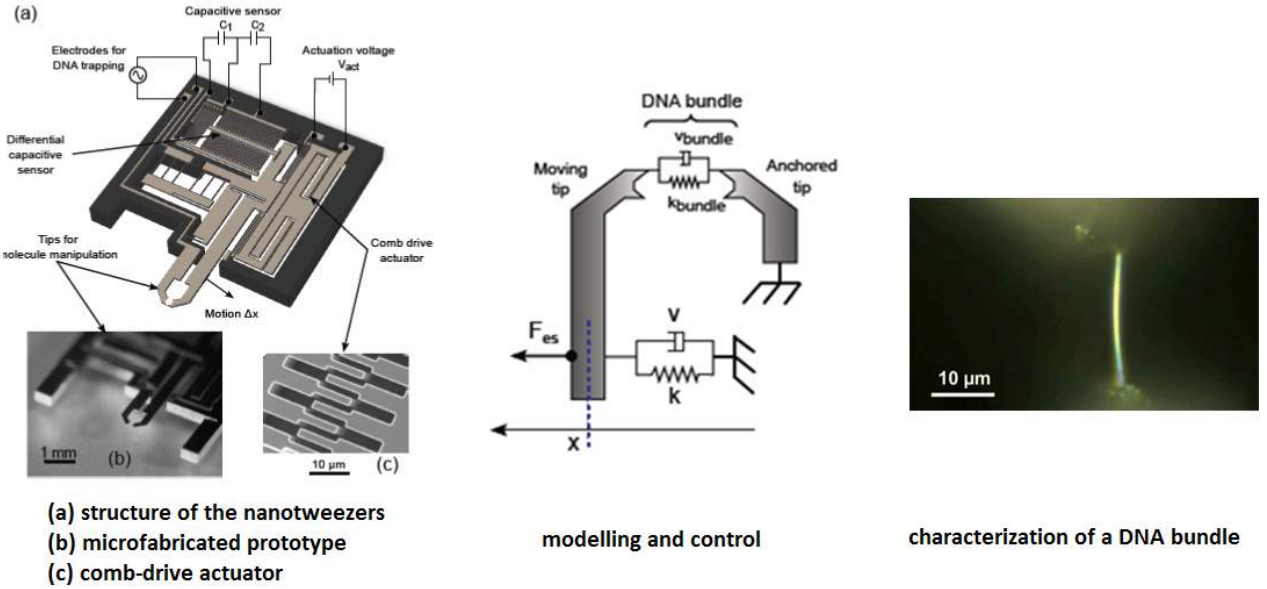
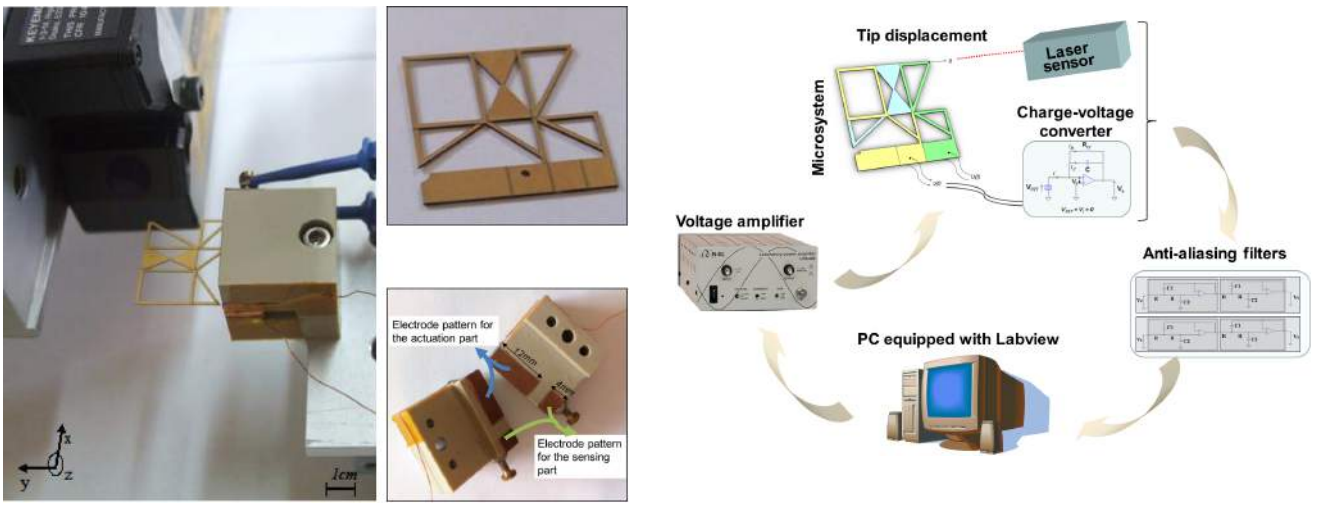


(a) structure of the nanotweezers
(b) microfabricated prototype
(c) comb-drive actuator

modelling and control

characterization of a DNA bundle

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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Bio-Chip at the nanoscale

MN2S (Micro Nano Sciences & Systems)

A biosensor is a device that uses a biomolecular reaction to detect a target analyte. It physically combines the recognition element (receptor) with a transducer that translates the biochemical reaction between the receptor and its tar¬get into an interpretable physical signal. The MIMU team of the MN2S department is interested in various modes of transduction, among which the surface plasmon resonance (SPR) which can detect and quantify molecu¬lar interactions in real-time, molecular interactions. The global performances of such biosensors will depend on the sensitivity of the transducer, but the main bottleneck is governed by the biospecific interface which guarantees the ability of the biochip to operate in a real biological world and reach the required specificity.

Finally, and perhaps surprisingly, to investigate onto large library of samples of patients, an investigation at the nanoscale of the biochemical architecture is crucial for developing functional biosensors. The team has been exploring this nanoworld for biological and clinical purposes with the Clinical Innovation Proteomic Platform (CLIPP) since 2008.

Atomic force microscopy (AFM) is a technique which enables to assess changes in surface topography, biofilm homogeneity, protein surface coverage and protein 3D structure without any need of labeling. The coupling of SPR with the AFM is a promising way to perform a correlation between an average measurement at the macroscale of biological activity on the chip and the in situ visualization of nanoscale biological events.

Our team has developed a production line of nanostructured SPR gold-chips based on evaporation and sputtering methods of thin film deposition inside the MIMENTO technology center. From this environment, ultra-flat gold chips have been developed to combine the power of SPR and AFM techniques (top figure). By this way, we validate the 2D proteic grafting onto chemically functionalized gold chips and the functionality of the biological layer from few to 10^4 ligands per μm^2.

These results help us to establish highly optimized biochips devoted to the investigation of biomolecular interaction analysis between two possible proteic partners, one immobilized at the surface of the biochip and the other one free in solution under lateral flow experiments. Thus, in a collaboration with Inserm Unit 866 from Dijon Hospital and University of Burgundy, we recently assessed the unambiguous and direct interactions between proteins, like Pannexin 1, and receptors, like LXRβ, driven by exogenous agonists (drugs). The discovering of the relationship between proteins in presence of drugs, the qualitative study of their interaction and their sequential involvement in the cancer cells will allow to identify therapeutic protein targets and to develop specific drugs for future clinical trials.

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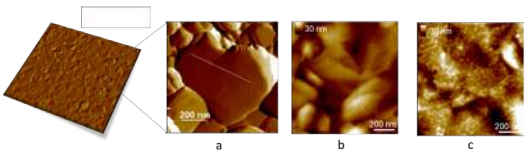
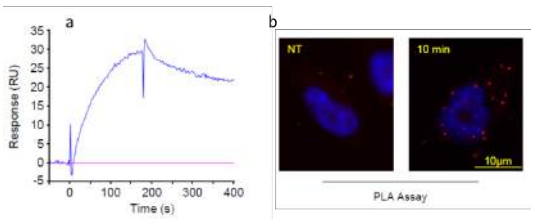


Antibody counting by AFM onto SPR gold chip functionalized by a Self-Assembled Monolayer (SAM) (a) and after bidimensional grafting at 140 Abs/µm2 (b) and 650 Abs/µm2 (c).



In vitro assay (SPR) demonstrating the binding of LXRβ to PANX1 protein chip (blue curve) and with control chip (pink curve) (a); ex-vivo assay (PLA) confirming the dynamic of the interaction under treatments (major increase of fluorescent dot after 10 min of incubation with LXRβ ligands).

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Acoustic cavity exhibiting quality factor greater than 1 billion.

TF (Time & Frequency)

Acoustic resonators have been widely used in on-board frequency sources for decades because of their relative simplicity of implementation. At room temperatures, such a system vibrating on a mechanical mode with frequency f greater than 1 MHz exhibits a quality-factor Q, i.e. the inverse of losses, limited by Qxf = constant. As an example, this constant is about 10^{13} for quartz crystal, i.e. Q >10^6 at 10 MHz. Actually, this relationship is derived from Akheiser's regime when intrinsic losses in the medium are dominant with regard to engineering losses (due to impurities, surface roughness, mechanical holders, etc.). In that case, absorption is mainly due to interaction of the acoustic wave with thermal phonons. When the temperature goes down below 10 Kelvins, Q increases and can reach incredible values of a few billion as demonstrated with bulk acoustic wave (BAW) quartz crystal resonators. Because of the increase of the thermal phonon lifetime, the mechanisms of phonon-phonon interactions at cryogenic temperatures are different from those at 300K: the absorption coefficient is changed, and in turn, Q does not depend on f anymore, according to Landau-Rumer's theory. Devices initially optimized to work at a few MHz at 300K have been tested up to 700 MHz, a 227th overtone, at 4K: the operating frequency is then just limited by defect or impurity diffraction.

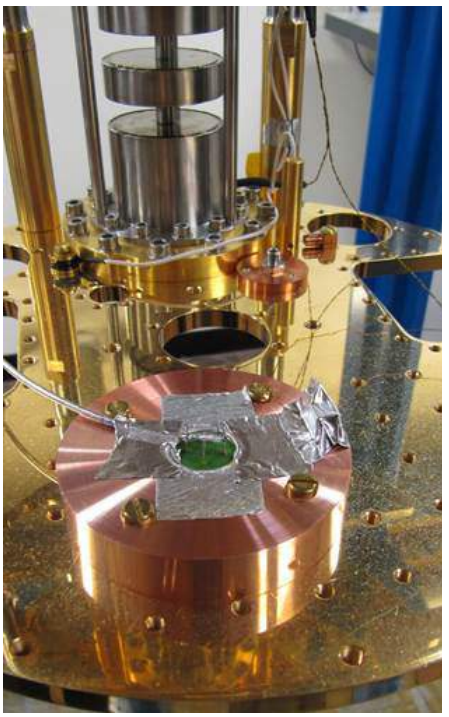
Besides their potential use in ultra-stable frequency sources, these low-loss phonon-trapping cavities offer extraordinarily large coherence times beyond the capability of any other competing technology. As optical cavities act as photon traps, bulk phonons may be resonantly confined in a crystal lattice to build a phonon cavity. As in the optical domain, low losses are also necessary in order to increase the interaction time between phonons. Thus, highly sensitive hybrid systems such as our resonators should be used as an experimental basis for a broad range of low-frequency, low-power physical experiments including quantum cavity electromechanics, quantum metrology, etc.

To achieve the operation of hybrid mechanical systems in their quantum ground state, temperatures approaching absolute zero are required so that the condition $f > k_B.T/h$ can be met (h: Planck const., k_B: Boltzmann const. See the Bose-Einstein distribution).

Although an average number of thermal phonons close to 6 has already been achieved with these quartz crystal resonators by cooling down the cavity down to millikelvin temperatures using a cryogen free dilution refrigerator, investigations are still in progress.

Moreover, the Nyquist's noise (due to quantum or thermal fluctuations) of such acoustic resonators has also been measured recently at cryogenic temperatures. The observation of intrinsic Nyquist fluctuations is an important step towards preparation of a BAW resonator in the quantum ground state.

FEMTO-ST is supported by Région de Franche Comté on this topic. This work is jointly conducted at the Time and Frequency Dept. of FEMTO-ST and at the School of Physics, The University of Western Australia, Perth, Australia. Collaborative relationships also exist with a team from Laboratoire Kastler Brossel, Paris.



A resonator under test in a cryogen free dilution refrigerator.

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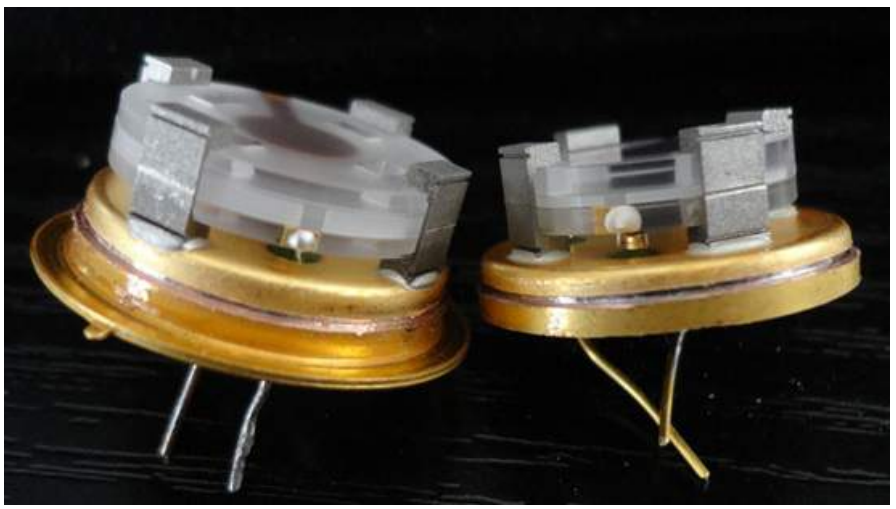

Typical 13.2 mm diameter resonators tested at cryogenic temperatures.

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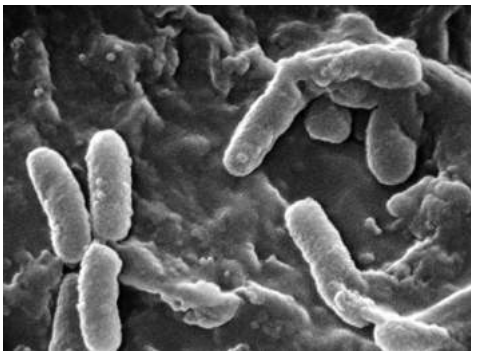
Bioinformatics

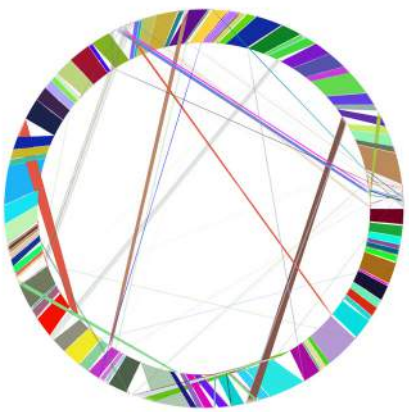
DISC (Computer Science for Complex Systems)

Between 1997 and 2009, 250 patients from the 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. 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 being about to be sequenced. Using unconventional computer science methods, we have demonstrated that the twenty genomes shared 6462 genes - 163 of which are specific to the precocious strain while 420 genes were only found in the late isolate.



A microscopic view of P.aeruginosa

These preliminary studies validate both the designed tools and the working assumption. We have shown that a given strain of *P.aeruginosa* evolves over 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 both home-made ad hoc software and the Mesocentre de Franche-Comté (France) computer facilities. These predicted genes have then been grouped by similar functionalities (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 bacterium - the collection of genes specific to the *P.aeruginosa* species. This knowledge will help bacteriologists to fight against this pathogen - such highly significant biological data, obtained thanks to original algorithms designed in the DISC department of FEMTO-ST Institute (in Besançon), will lead to a better understanding of the specificity of this bacterium and of the evolution of its genome over time.



Comparison between our two strains

After evidencing genomic recombination within this cohort of genomes, we have inferred an accurate phylogeny (evolutionary relations between these strains) based on the global 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, and studying 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 the 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.

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Contact

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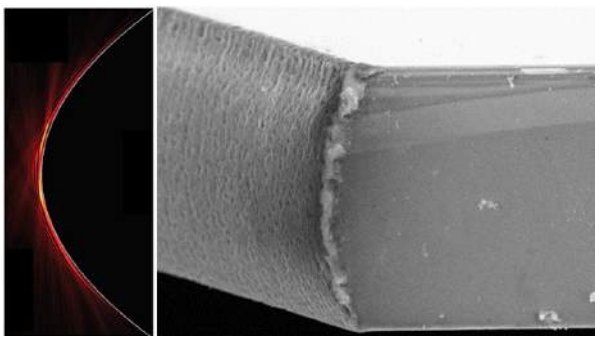
Taming intense ultrashort pulse nonlinear propagation in glass and applications

Optics

The Department of Optics at FEMTO-ST has developed in the last years an internationally recognized expertise in beam shaping of femtosecond laser pulses at micrometric scales. This allowed us to develop novel concepts for the field of laser material processing. Laser processing of transparent materials, like glass, is currently an important technological topic, because these materials have an increasing number of applications in consumer electronics (displays, smartphones, tablets), microelectronics, photonic chips or next-generation integrated 3D chips.

However, controlling energy deposition in transparent materials, i.e. where high laser intensities are located inside the material, is generally highly challenging because intense laser pulses distort along their propagation and during the laser-matter interaction: the propagation of such light beams is highly nonlinear. Since 2010, we have developed a novel approach to femtosecond laser material processing to actually take benefit of the ability of femtosecond pulses to process transparent materials. Our concept is based on using spatially shaped pulses that are propagation-invariant solutions of the nonlinear propagation equation. These solutions allow for the control of the energy deposition within materials, over extended zones in the depth of materials.



Curved beam propagating from top to bottom. (right) Curved Femtosecond laser processing of silicon

Developing novel propagation-invariant beams and investigating highly localized laser-matter interaction is the core activity of the NANOFLAM project. This project funded by the French funding agency ANR (Agence Nationale de la Recherche), runs over 2011-2015, and it involves partners from the Center for Theoretical Physics at Ecole Polytechnique (Palaiseau, FR) and from the Laboratoire Hubert Curien at University of Lyon-Saint Etienne (FR) .

FEMTO-ST obtained several important results that pave the way for novel concepts for studies of laser-matter interaction and laser processing. Starting with the development of highly curved beams, we demonstrated, for the first time, C-shape laser ablation, which has important applications to reduce the fragility of glass edges and avoids energy-consuming post-processing like edge polishing.

Specifically, we have investigated the propagation of Bessel beams and developed novel invariant solutions, like Bessel vortices where a tubular plasma has for the first time been generated on very long distances. Such results are promising for applications such as laser waveguide writing in glass, generation of guides in atmosphere for microwaves, or material compression by the intense cylindrical shock-wave emitted.

As another propagation-invariant solution, zero-order Bessel or Needle-like beams generate dense plasmas in glasses: in addition to opening novel opportunities for fundamental plasma physics within solids, they allow material processing at ultra-high aspect ratio (length to width ratio at sub-micro scales). For instance, nanochannels could be drilled in one single shot with an aspect ratio reaching 100:1 to 1000:1. An important application of this work is the ultra-high speed laser cutting of glass where cutting speed of several meters per second is reached with a highly reduced fragilization compared to other glass processing techniques (a technique protected by several FEMTO-ST patents).

Future applications are also currently developed through the European project TiSa-TD where high-power and high energy femtosecond lasers are considered for materials processing.

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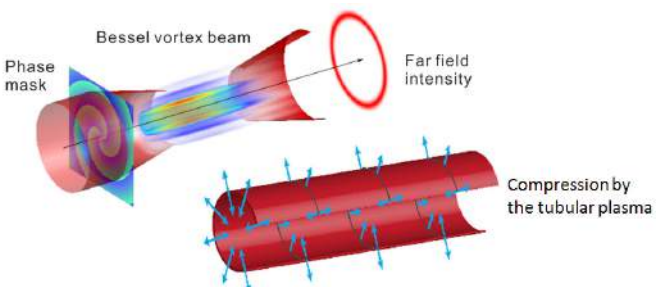

Top left: Concept of Bessel vortex beams generating a tubular plasma (yellow).
Bottom right: Concept of cylindrical material compression by plasma expansion and shock-waves.

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Combined heat and Power Generation: Latest Achievements

Energy

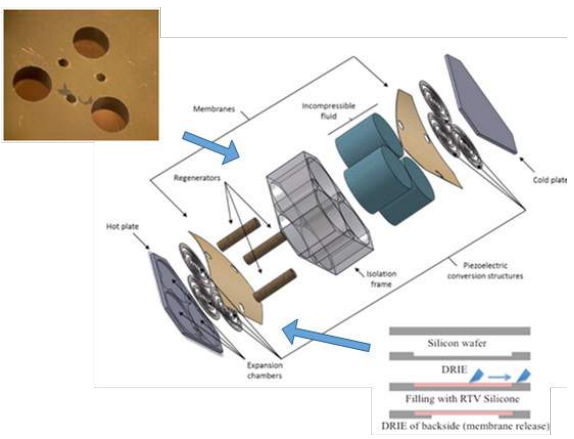
Micro scale combined heat and power (µCHP) generation is considered as a good candidate for energy savings and environmental benefits. It is emerging in residential, light commercial as well as remote installations for financial, environmental and energetic reasons. It is expected to reduce end user bills, CO2 emissions and primary energy consumption. Among the competing technologies in µCHP, hot air engines are good candidates due to their high theoretical efficiency, low maintenance requirements, fuel flexibility, and low noise level.

The technology developed at the ENERGY Department of FEMTO-ST includes Stirling (range power from µW to kW) and Ericsson (range power from kW to MW) engines.

Modelization, design and testing have needed several years of work to complete the latest Stirling prototype (i.e., WStirling Project1). The optimization of the overall system operable with primary fuels, such as natural gas or liquid fuels, has been performed. This system is based on the association of an external combustion engine and a rotary power generator to power Information and Communication Technology equipment.

Another concept under study is a device based on an Ericsson machine. The IndEHo project, in association with the Assystem company through a CIFRE thesis, aims at developing a small cogeneration system. The proposed system is characterized by its volumetric expansion chamber with metal bellows suitable for moderate cycle frequencies and internal air pressures. Another originality of the system is the external heat source. The ENERGY department of FEMTO-ST and the Assystem company are currently working on the realization of a feasibility demonstration via patents.

The Mistic project (Low Temperature Waste Heat to Electric Energy using Micro-Stirling Clusters) aims at developing enabling technology for waste heat recovery in industrial processes. The chosen concept consists in implementing clusters of miniature thermodynamic Stirling machines. The core technology is a multiphase piezoelectric smart membrane Stirling engine fabricated using mass MEMS machining, assembling and thin film technology. Expected performances allow a large fraction of electric energy to be extracted from the low



Mistic concept (Energy & MN2S Departments).

Latest Stirling prototype.

temperature waste heat. The relevance of the Stirling cycle for a microminiaturized generator has been demonstrated and basic underlying technologies for its fabrication are available through the project partners' facilities and capacities.

Considering the whole µCHP system, the heat source for the Stirling engine can also be obtained through a high-temperature fuel cell stack (Solid Oxide Fuel Cell – SOFC), using its thermal by-product. This innovative combined heat and power generation system has already been studied in the ENERGY department of FEMTO-ST as part of the FCLAB (Fuel Cell Lab - http://www.fclab.fr/) research federation. Obtained experimental results feature very high electrical (over 0.5) and exergetic (over 0.6) efficiency abilities.

Industrial and Academic Partners:
Orange Labs., Assystem, SYMME (Université de Savoie), UMI-LN2 (Université de Sherbrooke, Canada), MN2S/FEMTO-ST

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Success Stories

Interdisciplinary Research

Diagnostic, Prognostic & Health Management of Fuel Cell Systems

AS2M & Energy

Considered as a promising technology for chemical energy conversion into electricity, Proton Exchange Membrane Fuel Cells (PEMFC) are no longer remote from large scale deployment. However, some improvements are still required to extend the lifetime of these systems. Prognostics and Health Management (PHM) appears as a great solution to help tackling this issue, as it enables taking the right decisions at the right time in order to preserve the system and extend its lifetime until the mission is complete. The PHM of PEMFC is still a very recent research topic and FEMTO-ST is a leading institute in this area. Indeed, this new research field could emerge thanks to activities conducted jointly by the AS2M and ENERGY departments of FEMTO-ST, as parts of the CNRS research federation FCLAB. It is also currently explored as a part of WP5 of the Labex ACTION project.

For the past three years, FEMTO-ST has been leading or has been involved in projects about the PHM of PEMFC: a Franche-Comte Region project, a national ANR project, a European-funded project, and an ADEME project, all with leading industrial partners. Those activities allow to fund 5 PhD theses and 2 post-doctorates, developing advanced approaches for prognostics of Fuel Cells, and performing long duration tests with actual mission profiles. Current work includes the development of prognostics algorithms aimed at estimating the State of Health (SoH) of a Fuel Cell, as well as predicting its Remaining Useful Life (RUL): a model-based prognostics tool relying on Bond Graph and Energetic Macroscopic Representation, a physical prognostics approach based on electrical equivalence, a hybrid prognostics tool based on particle filters, and data-oriented prognostics tools based on neuro-fuzzy systems, reservoir computing and Extreme Learning Machines. Also, the development of this research theme has led to the organization of two dedicated events:

- The first international Summer School on "Diagnostics and Prognostics of Fuel Cell Systems", organized in Belfort, 01-14 July 2014, that brought together 58 attendees from 8 countries (https://propice.ens2m.fr/ecole-diag-pron-PAC.html);

- The IEEE PHM 2014 Data Challenge, an international competition that was focused on the estimation of the State of Health (SoH) and on the prediction of the remaining useful life (RUL) of a Fuel Cell (http://eng.fclab.fr/ieee-phm-2014-data-challenge/). Both Academic (from University) and Professional teams (from Industry) were encouraged to enter, and leading groups worldwide (Brazil, Germany, Korea, USA) were all registered.

All these activities are also developed in the framework of the FCLAB Research Federation (FR CNRS 3539). http://www.fclab.org

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DiMEMS, MicroElectroMechanical Systems

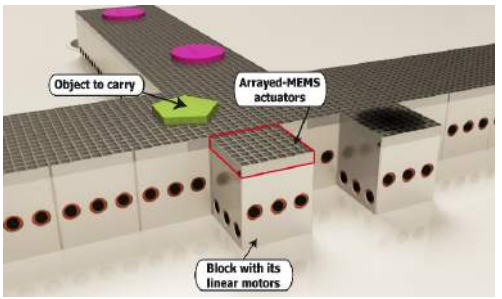
DISC & AS2M

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 integrated in airbag systems as well as in most of the recent smartphones or laptops, bubble ejection systems of inkjet printers or digital micro-mirror devices (DMD), a technology used for projection displays. As can be seen from 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.

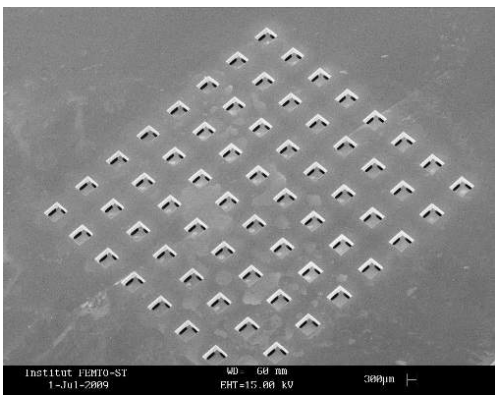
The main interest of MEMS is that they can be mass-produced, which is true for single MEMS as well as for distributed ones (DiMEMS). It is therefore necessary to think of scalability up to millions of units when evoking distributed MEMS. Due to their small size, their low cost and the fact that they can be mass-produced, millions of units can be used in a very small space. For example, a volume of less than 1mm^3 of 1µm-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 a central processing unit but this can become a bottleneck, both in the hardware and software parts. The use of the expression 'distributed intelligent MEMS' has been suggested when referring to such an architecture.

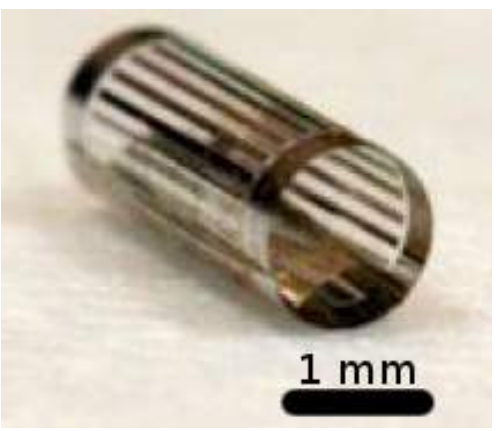
Distributed intelligent MEMS systems will be composed of thousands or even millions of systems which will raise new scientific challenges both for controlling and for programming such large ensembles. Scalability is therefore the main issue in this kind of new device. Distributed intelligent MEMS have 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).



Object sorting and conveyance with Smart Blocks



A view on one prototype of Smart Surface



A Claytronics atom (with the permission of Emre Karagozler, CMU). A view on one prototype of Smart Blocks

Several projects have been initiated at FEMTO-ST to study and develop these new systems. Two multi-disciplinary projects have been initiated (Smart Surface and Smart Blocks) to study objects conveyance using distributed intelligent MEMS. Another project called "Coordination and computation in Distributed Intelligent MEMS (CO2Dim)" studies the computer science part of DiMEMS systems. These projects are or have been funded by the National Agency for Research (ANR).
Another multi-disciplinary research topic concerns prognostic health management of distributed MEMS to detect, predict and cope with failures of distributed MEMS using distributed information.
Together with Carnegie Mellon University, we are building the next generation of programmable matter within the Claytronics project. With the help of the Labex Action, we are designing VisibleSim, a simulator for the Claytronics project which could also target any kind of modular robots or DiMEMS system. Finally, we are studying a new kind of wireless network called nano-communication network using 1-10 THz bandwidth in order to integrate them into programmable matter.

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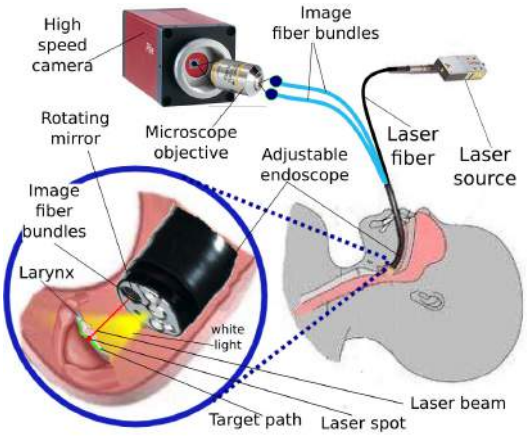
µRALP

Robot-Assisted Laser Phonosurgery

AS2M & Optics

The µRALP project (Micro-Technologies and Systems for Robot-Assisted Laser Phonomicrosurgery) is a collaborative project funded by the European Union through the 7th Framework Programme (FP7) and its « CT-2011.2.1 - Cognitive Systems and Robotics» subprogram. Started in January 2012 and ended in March 2015, it was devoted to the robotic assistance to the laser surgery of the vocal fold. Coordinated by the Istituto Italiano di Tecnologia (Genova), it involved two teams at FEMTO-ST (MiNaRoB/AS2M and PIM/DOptique) as well as the Leibniz University in Hanover, the University Hospital (CHRU) in Besançon and the ENT department of the University of Genova.

Lasers form an increasingly common tool for precision treatment of pathological conditions on delicate and vital human organs. Laser phonomicrosurgery, which is a suite of complex otolaryngological surgical techniques for the treatment of minute abnormalities in the larynx, is one such example. However, laser aiming control for this procedure relies completely on the dexterity of surgeons, who must operate through a microscope and deal with its associated poor ergonomics, and this can have a strong impact on the quality of the procedures. In addition, the laser beam is directed from a comparatively large range (400mm), resulting in accuracy and consistency problems, and requiring extensive surgeon training. In µRALP, a redesign of this surgical setup was proposed to create an advanced augmented micro-surgical system through research and development of real-time cancer tissue imaging, fluorescence-based diagnosis, surgeon-machine interfaces, assistive teleoperation, intelligent (cognitive) safety systems, and augmented-reality. From an optomechatronic point of view, the concept developed within µRALP is an endoscope which comprises a laser brought to the tip by a fiber, a fast scanning laser micromanipulator and a stereoscopic high-speed and multimodal imaging system.



The scientific and technical achievements of FEMTO-ST within this project are many:

- Design and realization of an optic assembly made of a pair of fiber bundles connected to a high-speed camera by appropriate optic components, allowing for fluorescence imaging and high-frequency stereoscopic laser tracking;
- Design, realization and low-level control of three functional laser micromanipulators;
- Use of epipolar geometry for augmented reality to the surgeon;
- Design and implementation of a stereoscopic image-based laser controller using trifocal geometry;
- Design and implementation of a fast image-based path tracking laser controller using;
- Nonholonomic constraints;
- In tight collaboration with CHRU Besançon, fluorescence analysis of vocal fold exereses;
- Validation of the image-based controllers of the laser micromanipulator in cadaver trials.

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Optical microwires and surface acoustic waves make tiny sensors possible

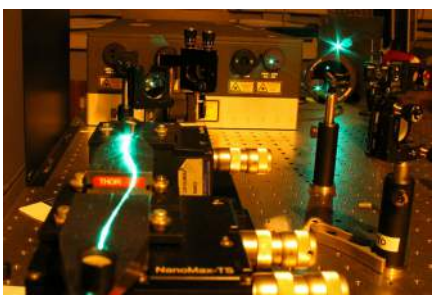
OPTICS & MN2S

Researchers at Optics and MN2S departments, working in collaboration with colleagues from the Charles Fabry Laboratory in Orsay, have demonstrated a new type of Brillouin light diffusion driven by surface acoustic waves in tiny optical fibers fifty times thinner than a strand of hair. This phenomenon, which varies according to the fiber's environment, could be used to develop sensors that are innovative and highly sensitive.

Optical microwires are silica fibers tapered down to a small size with an approximate diameter of one micrometer or even less. To produce these tiny objects, researchers at the Charles Fabry Laboratory heated and stretched optical fibers used in telecommunications, with an initial diameter of 125 micrometers. The remainder of the study was carried out at the Femto-ST Institute in Besançon. By injecting a laser beam in these silica microwires, the researchers observed a new type of light scattering, involving surface acoustic waves. This observation was subsequently confirmed by a numerical simulation, which helped verify the physical mechanism at play.

Since the diameter of the fibers is smaller than the wavelength of the light used (1.5 micrometers, in the infrared), the light is extremely confined inside. As it travels, it infinitesimally shakes the wire, displacing it by a few nanometers. This distortion gives rise to an acoustic wave that travels along the fiber surface at a velocity of 3,400 meters per second, according to the results of the researchers. The wave in turn affects the propagation of the light, as part of the light radiation returns with a different wavelength in the opposite direction.

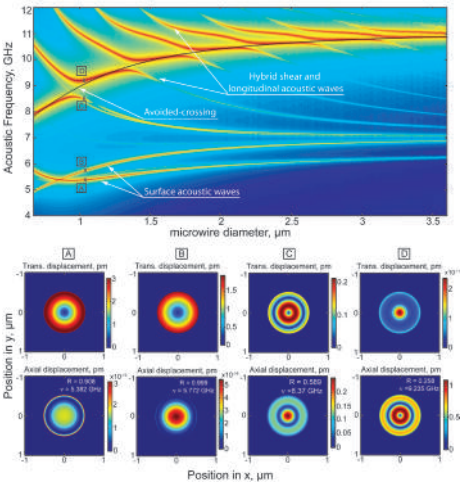
This phenomenon had never been observed previously, for it only occurs when light is confined in a subwavelength-diameter fiber. In standard optical fibers, light travels essentially in the core of the fiber (with a 10-micrometer diameter), and consequently does not generate surface waves.



Instruments at the Femto-ST institute, used to guide a blue laser beam at 450 nm into the optical microwire.

Since the waves generated by the confinement of the light travel along the surface of the microfibers, they are sensitive to environmental factors such as temperature, pressure and ambient gas. This makes it possible to design highly sensitive and compact optical sensors for industry. These results also help improve our knowledge of the fundamental interaction between light and sound waves in sub-wavelength waveguides.

These major advances in photonics and phononics arise from a long-standing and fruitful collaboration jointly conducted by researchers from the Nonlinear Optics and the MicroInstrumentation, Nanosciences and Waves (MINANO) groups at FEMTO-ST.



Numerical simulation of the acoustic wave spectrum in silica microwire. White arrows indicate the surface and hybrid acoustic waves, and the anticrossing points due to the strong coupling.

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