FEMTO-ST
2017
ANNUAL REPORT

femto-st
SCIENCES & TECHNOLOGIES

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

This Annual Report aims at presenting a brief and up-to-date overview of the FEMTO-ST institute's activities. It highlights some of our many successful 2017 achievements at the scientific and technological levels through a few sampled key facts.

FEMTO-ST is a public research institute located in the Bourgogne Franche-Comté region, in eastern France, next to Switzerland and Germany. It comprises 7 scientific departments (robotics & automation, digital information science, energy, applied mechanics, micro-nano-sciences and systems, optics, RF and microwave metrology), with on average 750 staff members (PhD students, postdoctoral fellows, technicians, engineers, administrative staff, researchers and professors). FEMTO-ST members are essentially employed by four different French public research and higher education institutions: the National Centre for Scientific Research (CNRS), the University of Franche-Comté, the National Engineering Institute of Mechanics and Microtechnology and the University of Technology Belfort-Montbéliard. The last three have now been brought together under the common banner of a unique federal regional university, University Bourgogne Franche-Comté (UBFC).

Our activities obviously cover many different themes within the broad discipline of engineering science, from fundamentals to applications. Each scientific department dedicates concentrated efforts to obtain world class scientific results in its own area. Beyond this internationally recognized, focused expertise, we are also firmly dedicated to cross-disciplinary interactions whenever it appears relevant and with highly innovative scientific and technological breakthrough potentials.

The FEMTO-ST institute aspires to lead academically, but we also take seriously the social role of a large research institute like ours. We have tried to highlight this latter strategic ambition through a few examples of interactions with industrial partners, along with our contributions to the birth of spin-off companies, whose innovative activities are directly related to our scientific achievements and technological know-how. It has been difficult to be both exhaustive and brief in this overview of our achievements. But we hope that the reader will be able to understand the depth of our work through the few sampled examples.

At FEMTO-ST, the work of highly professional and passionate people has made possible our excellence in research.

I would like to thank all members of FEMTO-ST for their continued commitment to our goals, and their essential contributions to the many successes we have achieved. I hope the reader will enjoy going through this 2017 Annual Report which shows the fascinating science we are seeking to create every day at FEMTO-ST. My wish is that this document succeeds in triggering new and fruitful interactions, at the academic, industrial, or societal level in the near future.

Laurent LARGER
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A BROAD RANGE OF MASTERED SCIENTIFIC EXPERTISE

FEMTO-ST IS STRUCTURED IN 7 SCIENTIFIC DEPARTMENTS IN WHICH RESEARCH TEAMS ARE WORKING.

WE ALSO ENCOURAGE PLURIDISCIPLINARY RESEARCH ACTIVITIES IN COLLABORATION BETWEEN DEPARTMENTS.

APPLIED MECHANICS

MATERIALS, SURFACES, PROCESS, STRUCTURES

MICROMECHANICS, MICROFABRICATION

FONCTIONALISATION, SMART STRUCTURES

SUSTAINABILITY, RELIABILITY, BIO-COMPATIBILITY

AS2M

MICROROBOTICS, MECHATRONICS

AUTOMATION

PROGNOSTIC & HEALTH MANAGEMENT (PHM)

DISC

PARALLEL AND DISTRIBUTED COMPUTING

FORMAL METHODS FOR SOFTWARE ENGINEERING

HIGH PERFORMANCE COMPUTING

DISTRIBUTED SMART MICROSYSTEMS

ENERGY

HYDROGEN-ENERGY

ELECTROMAGNETIC CONVERTERS

THERMAL MACHINES

METROLOGY AND ENERGY MANAGEMENT

MN2S

MICRO- OPTO- ELECTRO-MECHANICAL SYSTEMS

PHONONIC AND MICROSCOPY

NANOSCIENCES AND NANO-STRUCTURED MATERIALS

BIO-MICROSYSTEMS

OPTICS

NONLINEAR PHOTONIC

COMPLEX OPTOELECTRONIC SYSTEMS

NANO-PHOTONIC

TF

OSCILLATORS/ RESONATORS

TIME & FREQUENCY METROLOGY

MICROWAVE SYSTEMS AND SENSORS

EIPHI, THE FIRST UBFC GRADUATE SCHOOL, COORDINATED BY FEMTO-ST AND ICB (LAUNCH IN SEPT. 2018)

The University Bourgogne Franche-Comté (UBFC) is a federal university created in 2015 whose objective is to gather at the academic level, under a unique and greatly strengthened international visibility, all higher education institutions within the Bourgogne Franche-Comté Region. The creation of this new unified regional academic landscape is implemented through a coherent and joint restructuring of the regional research assets along three priority axes, among which the first axis is referred as "Advanced matter, Waves, and Smart systems". The FEMTO-ST institute and the ICB laboratory are two major UBFC research institutions with high international recognition in this field. These two regional public research laboratories (together with LNIO in the Grand-Est region) had already decided in 2011 to join forces through a common 10-year strategic research program granted by a national call for excellence in research known as Labex (Laboratory of Excellence), with a project named ACTION.

In 2017, FEMTO-ST and ICB decided to strengthen further their fruitful scientific collaboration through another joint application for a new national call for academic excellence dedicated to the creation of Graduate Schools. The Graduate School project named EIPHI (Engineering and Innovation through Physical sciences High technologies and cross-disciplinary research: $e^{i\phi}$) is the first one to appear under the UBFC banner. It was selected among very few other proposals in France, and granted a M€ 14 program over 10 years. The concept of EIPHI is to provide attractive international MSc and PhD programs of excellence, based on the scientific expertise available at FEMTO-ST and ICB. EIPHI stands out from other French graduate schools by the fact that it aims to strongly focus on an interdisciplinary MSc and PhD teaching, training and research program targeted at high added value for the graduate students. The programs will focus both on original and "niche" research areas (for which we are recognized as worldwide experts), as well as on their related innovative cutting edge technological solutions intended for the industry of the future. Important efforts in the program will be pushed toward a synergy between theoretical skills and experimental ones. EIPHI will be strongly benefiting from several platforms and high technology facilities available in the laboratories, reaching many different high tech application sectors (photonics, microrobotics, energy and sustainable technologies, integrated sensors and complex smart systems, programmable matter and software integrity, RF & microwave metrology, clean room micro-nano-fabrication, advanced matter fabrication and characterization, etc.). Students will be already established in the labs already from their 1st year of MSc, in close connection with the research teams.

EIPHI graduate school also intends to develop strong links with high-tech industrial partners (at the local, national and international levels), thus claiming an important dedication toward economic and societal impacts through employability, innovation and start-up creation, exploiting and valorizing the internationally renowned scientific expertise of FEMTO-ST and ICB.

More information

http://www.ubfc.fr

EIPHI

Engineering and Innovation through Physical sciences, High-technologies and cross-disciplinary research

Graduate School

UBFC

UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ

femto-st SCIENCES & TECHNOLOGIES

cnrs

ICB

CONTENTS

THE 2017 DWIGHT NICHOLSON MEDAL AWARDED TO PROF. JOHN M. DUDLEY

OPTICS

Professor John M. Dudley was awarded the Dwight Nicholson Medal for Outreach of the American Physical Society for outstanding leadership in the International Year of Light(2015) and for optical science and engineering outreach on a global scale. By awarding this medal the American Physical Society recognizes a physicist who has successfully stimulated the interest and involvement of the general public in the progress of physics and hascreated a special opportunity that inspires the scientific development of students and colleagues. The International Year of Light 2015 was a tremendously successful global initiative with thousands of events in over 140 countries reaching millions of people worldwide. United by the interdisciplinary theme of light, it brought together a diverse range of participants along with UNESCO, all committed to raising awareness of how light science and technology provide solutions to the many challenges facing the world today.

Professor Dudley continues to work closely on global outreach with UNESCO, and is chairing the first annual International Day of Light celebration planned on 16 May 2018 following its official Proclamation at the General Conference of UNESCO in November 2017.

More information

https://www.aps.org/programs/honors/awards/nicholson.cfm
http://www.light2015.org

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THE 2017 ANDRÉ BLONDEL MEDAL AWARDED TO PROF. DANIEL HISSEL

ENERGY

The André Blondel Medal has been awarded annually since 1942 by the Electrical Engineers Society (SEE) in honour of the eponymous scientist. It promotes authors of exceptional work in the fields of science and the electrical industry in the broad sense. One of its characteristics is that the laureates must be under 45 years old, which makes it possible to highlight "young" scientists.

In 2017 Prof. Daniel HISSEL, head of the SHARPAC (Hybrid & Fuel Cell systems, Electrical Machines) research team and Director of FCLAB research federation, was awarded for “his crucial contributions to the design and management of energy systems using hydrogen and fuel cells”.

More information

http://www.fclab.fr
https://www.see.asso.fr/distinction/20728_medaille-blondel-2017

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IFAC AWARD DELIVERED TO PROF. YANN LE GORREC

AS2M

The award for distinguished service from the International Federation of Automatic Control (IFAC), was delivered to Yann Le Gorrec on 10th July in Toulouse during the IFAC World Congress. This award is given to worthy scientists involved in the IFAC community. Yann Le Gorrec has been awarded this honour for his involvement as an active member in three IFAC technical committees respectively on Control Design, Distributed parameter systems and Non Linear Control systems.

For ten years he has been developing research on port Hamitonian formulations for the modelling and control of non linear and distributed parameter systems. His research group in AS2M department of FEMTO-ST is among the most active and recognized at the international level on this topic. The results of his group have been successfully applied to many fields of research, such as micro-mechatronics, smart systems acoustic systems and irreversible thermodynamics. This work has grown out of many significant projects from competitive calls: ANR/DFG project, European Training Network Project.

Yann Le Gorrec was the Chair of the National Working Group on Partial Differential Equations of GDR MACS from 2006 to 2013 and the Co-Chair of the Technical Committee on Distributed Parameter Systems from 2009 to 2017. He was the Co-Chair of the NOC of the first Workshop IFAC Control of Systems described by Partial Differential Equations in 2013, of the first Workshop IFAC Thermodynamic Foundation of Mathematical System Theory in 2013, the first IFAC summer school on Control of Distributed Parameter Systems in 2016, and the fourth IFAC Workshop on Lagrangian and Hamiltonian Methods for Non Linear Control in 2015. Being a member of numerous international program committees, Yann Le Gorrec is the IPC Chair of the next IFAC Workshop LHMNLC18.

More information

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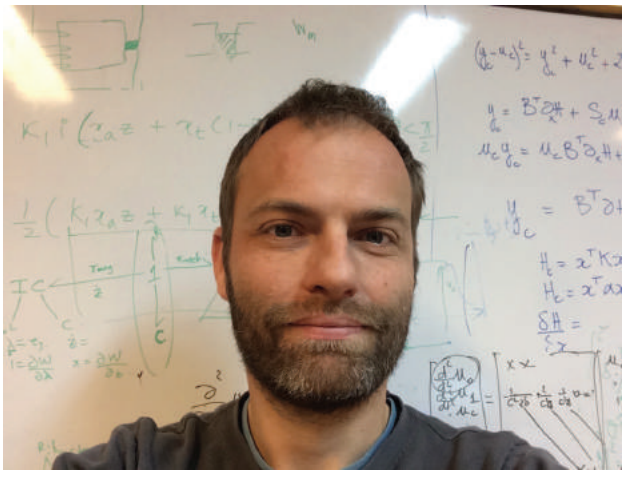

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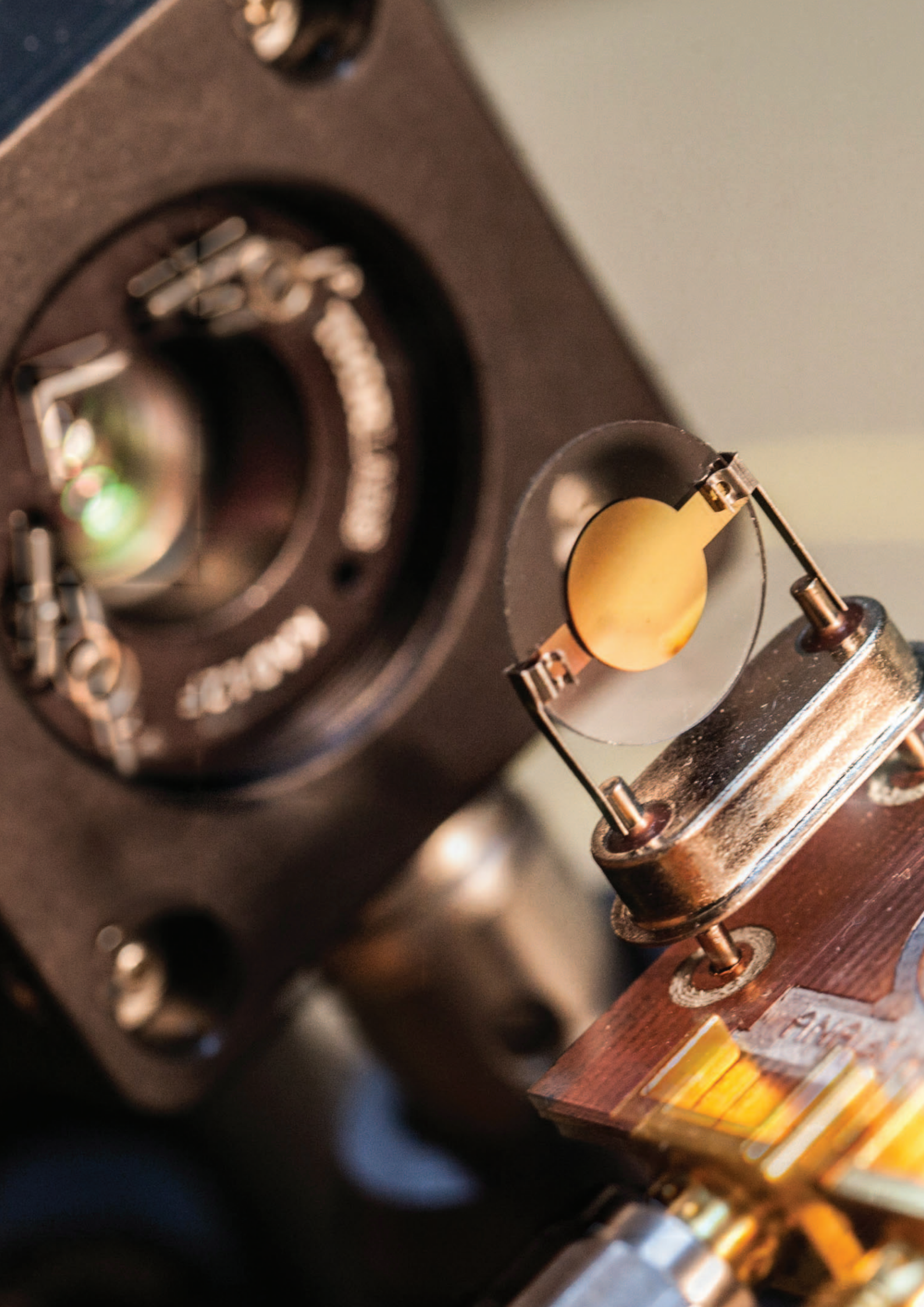

VISION BASED METROLOGY AT SMALL SCALES IN SCANNING ELECTRONIC MICROSCOPE

AS2M

Metrology of a 3D position is an important issue, in both air and vacuum, in the framework of small object manufacturing and instrumentation at small scales. Indeed it enables the performing of robotic manipulation as well as quality control. It is particularly challenging when using images from a scanning electron microscope (SEM) because the latter is modelled by parallel projection - i.e. images are obtained from rays parallel to the optical axis which avoids perspective effect but leads to three ambiguities: invariance to depth, invariance to the product out-of-plane rotation by depth, invariance to reflection.

A solution to this problem has been developed that combines microscopy, computer vision and robotics. It is practical, accurate and robust compared to literature solutions. It comprises the 3D positioning of the object with respect to the microscope, by controlling the robot along with performing the dynamic autofocus of the microscope in order to acquire more than two images. The higher number of images provides redundant information and leads to more accurate and robust final results. From the obtained images, a self-calibration is implemented, based on nonlinear optimisation with a global search approach. It enables to recover the model of the microscope and the motions, with accuracy. Self-calibration avoids the tedious and rigid step of manual calibration and it is accurate and practical. From auto-calibration, original linear rectification and triangulation enable the measurement of 3D points, i.e. the 3D structure of the object. The solution has been applied with success to the edge of a cutting tool, two pollen grains and a deposit of polypyrrole. It is optimised to be fast enough: from four acquired images it can deliver up to ten 3D dense clouds per second. The developed solution can also be applied to photon microscopes with telecentric lenses, i.e. in the air. Indeed compared to SEM these lenses also work with parallel projection.

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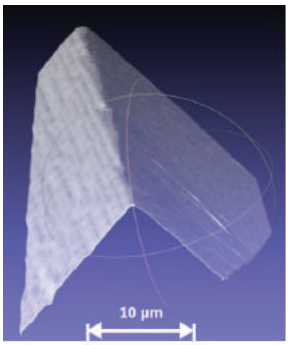

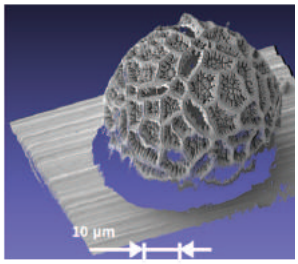

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INTRACORPOREAL MICROROBOTICS

BEST THESIS AWARD IN ROBOTICS

AS2M

Established in 2012, MiNaRoB, the Biomedical Micro/Nano-Robotics group of the AS2M department, develops novel sensing and control methods as well as microtechnologies for robot-assisted regenerative medicine and dexterous robot-assisted surgical interventions in the patient's body, with high care to minimize undesired side effects (minimal impact surgery or minimally invasive surgery). Beside various projects in high-speed cell sorting (ANR PRCI CoDiCell, ERDF Mimedi) and oto-rhino-laryngology (FP7 µRALP, ANR NEMRO, ANR µRoCS), the group is also undertaking interventional endoscopy in the digestive tract. Within the ANR Labex ACTION and in association with the MOEMS group of the MN2S department, MiNaRoB develops an active OCT endomicroscope.

The concept consists in a robotised flexible endoscope – holding an in-silico Optical Coherence Tomography probe and a bi-manual micromanipulator – which is guided by the images provided by both endoscopic cameras and the OCT probe.

This project received a lot of attention in 2017. First, as a recognition of clinical relevance, MiNaRoB (with the MOEMS group and the ICube laboratory in Strasbourg) received its first INSERM funds (ROBOT: Robotics and Optical coherence tomography (OCT) for optical BiOpsy in the digestive Tract). One of the technologies developed in the project is a soft microrobot, in tubular form, which can continuously deform thanks to embedded microactuation, made of electroactive polymer. This concept was developed in Taha Chikhaoui's PhD thesis, which received in November 2017 the Best 2016 PhD award from GdR Robotique, the French Research Network in robotics. A paper from this work was also awarded the Best Poster Oral Presentation at the 2017 Hamlyn Symposium on Medical Robotics (Imperial College, London), the best conference on translational research in medical robotics.

Reference

M.T. Chikhaoui, A. Cot, K. Rabenorosoa, P. Rougeot, N. Andreff, Towards Biocompatible Conducting Polymer Actuated Tubes for Intracorporeal Laser Steering, Hamlyn Symposium on Medical Robotics, Imperial College, London, June 2017.

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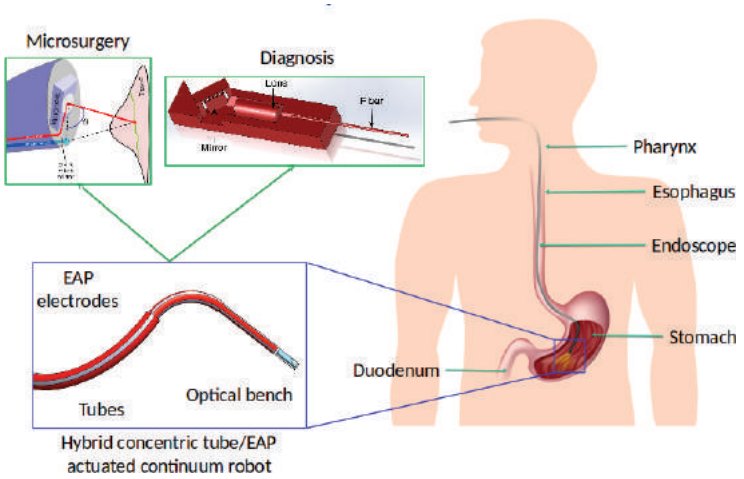

Hybrid concentric tube/EAP actuated continuum robot

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FOUNDATION FOR A SERIES OF EFFICIENT SIMULATION ALGORITHMS

DISC

Computer systems are often modelled by finite transition systems, i.e. finite sets of states and transitions between these states, as shown by the figures below. The notion of simulation is an established method of comparing the behaviours of two different transition systems in order to find out whether the first one can do more than the second one.

Another major use of this notion of simulation is to reduce the size of a given transition system. Indeed, when a first state simulates a second state this implies that from the first state one can do everything that can be done from the second state The consequence is that if two states prove to simulate each another reciprocally it is no longer necessary to distinguish between them. By doing so, we reduce the number of states that must be considered as really different and thus the size of the given system. In the figure below, the system on the right is the reduction of the system on the left.

Among several real examples, a system evolving through nearly 150 000 different configurations has been reduced, thanks to this notion of simulation, to a system evolving in less than 1 000 configurations. It is therefore much easier to analyse this reduced system to check its good behaviour or detect errors.

The difficulty is that the algorithms calculating the largest simulation in a system were either memory efficient yet not very fast, or fast yet using a lot of memory and therefore not applicable on large systems. Since 2007, the existence of an algorithm that is both fast and efficient in memory has been an open problem. We respond positively to this question and, above all, highlight the foundations that will allow to propose new compromises, both theoretical and practical, between computing time and required memory for these algorithms.

Reference

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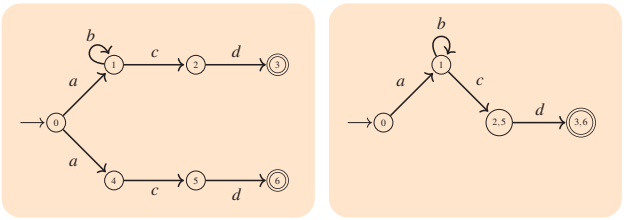

Example of problem reduction of finite transition systems

CONNECTED FIREFIGHTERS IN THE INTERNET OF THINGS AGE

DISC

Tomorrow, firefighters will have access to greater safety thanks to the latest technological means which are investigated in the Interreg RESponSE project (sensor networks for fire brigade health and safety). It is therefore a whole army of sensors that RESponSE will raise in accordance with a strategy dedicated to the safety of fire soldiers. Devices intended for men will monitor their temperature, fatigue or heart rate, and devices installed on sensitive buildings will provide information on external temperature and structural deformation when a fire occurs.

In this configuration, all the firefighters are connected to each other and to the buildings. They become automatic emitters of warning signals when they are in distress, they are able to react to information received from a colleague or to adapt their action to the fire evolution.

Furthermore, throughout the experimental test the firefighters will systematically wear connected clothes during their on-call periods in order to assess the contribution of these new technologies to their protection.

RESponSE is drawing on the skills of academic and industrial partners, reflecting the excellence and complementarity of the French-Swiss Jura Arc: FEMTO-ST (DISC) for the distributed algorithmic and wireless sensor network aspects; EPFL (école Polytechnique Fédérale de Lausanne) for embedded computing and communication between devices; sports science specialists from the C3S lab for technical choices in body sensor networks and data analysis; philosophers from the RECITS transverse initiative in Human Sciences at FEMTO-ST (see p.20) to study societal acceptability; other FEMTO-ST researchers from the AS2M Dept. for diagnosis and prognosis of changes in fire context; the Frec|n|sys spinoff for the design of temperature and deformation sensors in extreme conditions; the Swiss company KIZY TRACKING to build the tracker for firefighters' location; and, finally, thirty firefighters from the Doubs county. Launched in September 2016 for a 3-year period, RESponSE has received ~€1 Million in Interreg funding for its implementation.

More information

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APPROXIMATE-CENTROID ELECTION IN LARGE-SCALE DISTRIBUTED EMBEDDED SYSTEMS

BEST PAPER AWARD

ADVANCED INF. NET. & APPL. CONF, CRANS MONTANA (CH)

DISC

Programmable matter consists of a collection of numerous mobile microrobots interacting together in order to modify their global shape. FEMTO-ST is developing advanced distributed algorithms to optimise the communication between the robots, consisting of a large dynamic and distributed network.

Many distributed algorithms require a specific role to be played by a leader, or single node in the system. It is particularly the case in programmable matter when it is implemented as a set of modular robots. In this case, many operations are needed to find the centre of the system.

Indeed, the choice of this central node has a direct impact on the performance. In particular, selecting a central node as the leader can significantly improve algorithm efficiency. Classical distributed algorithms require global information about the connectivity network to elect a centroid node. Thus, they are not suitable for large-scale distributed embedded systems with scarce computation, memory and energy resources.

We present E2ACE, an Effective and Efficient Approximate-Centroid Election algorithm that uses O(1) memory space per node, O(d) time and $O(mn^2)$ messages of size O(1), where n is the number of nodes, m the number of connections and d the diameter of the system. E2ACE first uses probabilistic counting to estimate the farness of all nodes, where the farness of a node is the sum of its distances to all the others. This method is approximately equivalent to computing the theoretical farness of all nodes but at less expense in terms of computations and communications. The node of minimum distance is then elected as the centroid. We evaluate our algorithm on the Blinky Blocks modular robotic system using simulations. Experimental results show that E2ACE scales well in terms of accuracy, execution time and number of messages. We demonstrate that E2ACE is more accurate than the existing algorithm with similar complexity results.

Reference

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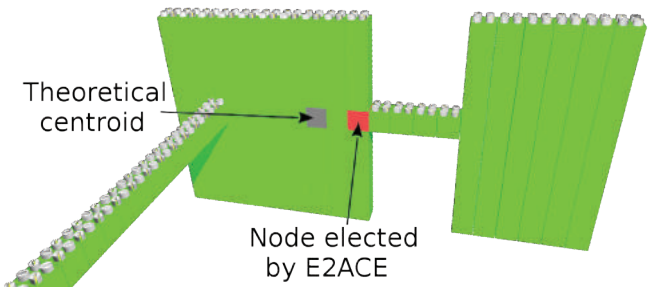

Example of the determination of the central node (Node elected by E2ACE) in a tridimensional network of microrobots.

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BRILLOUIN SPECTROSCOPY OF OPTICAL MICROFIBERS AND NANOFIBERS

OPTICS

Researchers from the Optics department in collaboration with the Laboratoire Charles Fabry in Orsay (France), have demonstrated a nondestructive and all-optical method to measure the sub-wavelength diameter of tapered optical fibres including both the uniform and transition sections These hair-like slivers of silica glass, fabricated by tapering standard telecom optical fibres, enable enhanced optical confinement and generate a very large optical evanescent field. As a consequence, optical micro and nanofibres are widely used in a vast number of applications ranging from quantum and ultra-cold atom optics to optical chemical and biological sensing. However, most existing methods for characterising these nanofibres are either destructive or rather complex to implement. The method developed by the FEMTO-ST scientists is based on a direct and fast numerical analysis of the backward Brillouin spectrum measured using a highly sensitive single-ended heterodyne coherent detection. By injecting a telecom laser beam in a silica tapered optical fibre, the researchers observed several acoustic resonances due to compression, shear and surface acoustic waves generated by Brillouin scattering. This was performed in situ without any manipulation nor optical alignment of the optical microfibres. The measurement of fibre diameters ranging from 500 nm to 1.2 µm was achieved with sensitivity as high as a few nanometres. Such sensitivity usually requires the use of a Scanning Electron Microscope which is less handy. This new method may help for the design and characterisation of optical fibre tapers widely used in many applications such as optical sensing, atom trapping, quantum optics, and plasmonics.

Reference

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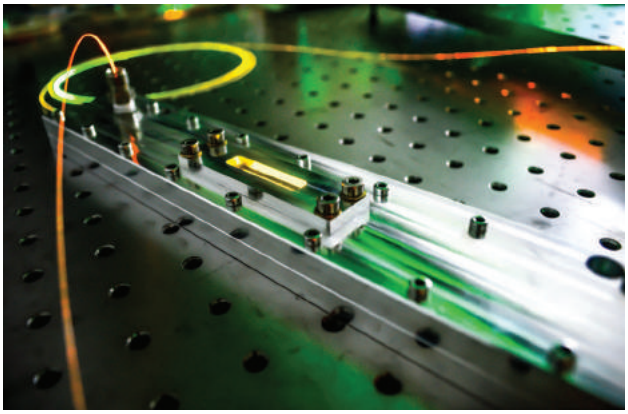

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RESERVOIR COMPUTING SPEEDS UP

OPTICS

The combination of all-new brain-inspired computing concepts and photonic components has led to the development of an optical processor capable of solving complex problems at ultra-fast speeds.

For some years now, the field of computer science has been undergoing a revolution since artificial intelligence is considered from the angle of artificial neural networks of new generations, particularly with deep learning, resulting from machine learning. The leading actors in the sector, such as IBM, Google and Facebook, have made it a major strategic development axis by recruiting the most cutting-edge researchers in the field. However, despite the tremendous recent boom in digital technologies, the Information Technology (IT) resources needed to process this massive data on the Internet are reaching the limits of modern computing units in terms of data processing speed and energy management efficiency. This is why, in addition to a computer science approach, a physical approach proposes new hardware and not software solutions to realise the processors of the future, intended to replace the current approaches dominated by programming in conventional computers. These theoretical concepts and physical architectures are respectively 80 and 60 years old.

This new neuromorphic computing concept, called Reservoir Computing, has been physically implemented on a photonic system with lasers, optical fibres, modulators and light detectors. Its computational ability, after a learning phase, has been successfully tested at FEMTO-ST in a standard speech recognition test. A record processing speed of nearly 1 million words per second was achieved. More fundamentally, the results obtained also concern the establishment of a model that creates a missing link between neural networks and signal processing concepts. This link highlights a practical method for finding solutions to the critical technological problem of dense neural wiring, naturally provided by synapses in the human brain.

Reference

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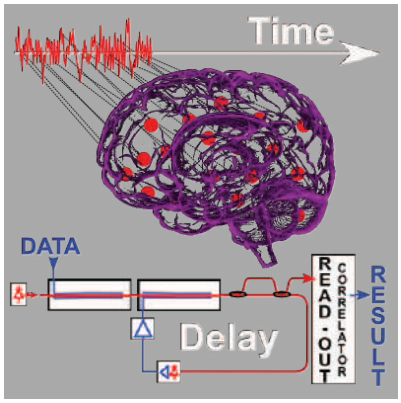

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MINI X-RAY SENSOR FOR HIGH-PRECISION MEDICAL APPLICATIONS

OPTICS

Using a tiny device known as an optical antenna, researchers from the nano-optics group of FEMTO-ST Institute have created an X-ray sensor that is integrated onto the end of an optical fibre just a few tens of microns in diameter. By detecting X-rays at an extremely small spatial scale, the sensor could be combined with X-ray delivering technologies to enable high-precision medical imaging and therapeutic applications. Like many of today's X-ray applications, the new X-ray sensor uses indirect detection. Rather than directly sensing X-rays, this method uses a special detector called a scintillator, which absorbs the X-rays and then emits light that is detected by an optical camera. Achieving indirect X-ray detection on a small scale is challenging because scintillators emit photons in all directions. Scaling scintillators down to a very small size implies that they will emit very few photons, making it almost impossible for the camera to catch enough photons at just the right angles. The researchers turned to optical antennas to help meet the challenge.

To make the X-ray sensor, the researchers used an optical antenna to connect a single mode optical fibre with a tiny cluster of scintillators. They fabricated the optical antenna, just a few microns wide onto the end of the fibre and grafted the scintillator cluster at its extremity. Light emitted from the scintillators hits the antenna and is directed into the fibre, where it travels to a remote optical detector. Although the X-ray sensor fabrication required a clean room facility, the process was neither difficult nor expensive. Researchers are currently working on procedures that might make it even easier to graft the scintillators onto the fibre antenna.

From their experiments, the researchers estimated that the sensor has a spatial resolution of the order of 1 micron which they are trying to increase to reach about 100 nanometers. This improved resolution would allow the device to distinguish chemical components in composite materials by using the fibre tip to conduct X-ray scanning microscopy. In addition to expanding the technology to work with the high-energy X-rays required for medical applications, the researchers are also investigating whether optical antennas could allow for faster X-ray detectors.

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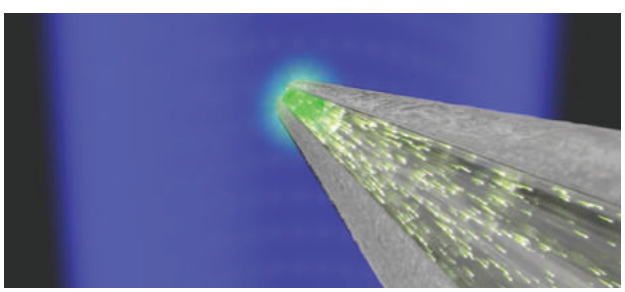

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MULTI-PHYSIC ANALYSIS OF ELECTRICAL MACHINES: HYBRID ELECTRO-MAGNETO-AERO-THERMAL MODELING

BEST PRESENTATION AWARD, INT. CONF. ON ELEC. MACHINES & SYS., SAN FRANCISCO

ENERGY

The design of electrical machines requires optimising the geometric and physical parameters currently requiring heavy complex multi-physic calculations. It should take into account nonlinear magnetic simulations, surface loss hysteresis and aero-thermal coupling.

FEMTO-ST, G2Elab (Grenoble) and LAMIH (Valenciennes) have developed an original scientific approach enabling the simulation of this multi-physic problem with a reduced calculation time. The model is based on three elements: (i) a two-dimensional (quasi three-dimensional) generalised nonlinear adaptive magnetic equivalent circuit (MEC), (ii) a loss surface (LS) dynamic hysteresis model and (iii) a three-dimensional aero-thermal simulation of Machines (ASEM). The multidisciplinary model has been validated on a magnet motor (16 kW @ 1,000 rpm), which can be used for automotive applications in electric/hybrid/fuel cell vehicles.

More specifically the first model (MEC) enables the magnetic state calculation in the magnet motor reducing the computation time in comparison with the numerical simulations. The second model (LS) has been built and compared with experimental data showing an error below 10% error. It was implemented in the Flux software of Altair (ex. Cedrat) as a post-processing module for the iron loss computation. The third model (ASEM) based on the thermal equivalent circuit, allows the temperatures determination in the magnet motor by taking into account the aeraulic behaviour and the power loss distribution.

Finally, the three models are combined in an iterative algorithm in order to provide an efficient multi-physic model. This work was supported by Renault-SAS (Guyancourt). This scientific study is related to the project COCTEL financed by the ADEME.

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EUROPEAN PROJECTS IN HYDROGEN

ENERGY

The FEMTO-ST SHARPAC team is involved in two new European projects funded in 2017 : the HAEOLUS project and the HYSCHOOLS project. Both projects are also operated in the framework of the FCLAB research federation.

NEW FCH JU PROJECT: HAEOLUS

Haeolus is a European collaborative project funded by the FCH JU initiative starting in January 2018. It aims at designing, building and operating the world's largest hydrogen production demonstration within the fence of a wind farm. The demonstration site will be the Varanger Peninsula in Norway, where enormous wind power resources remain unexploited because of the low grid capacity.

In areas with abundant wind resources, relatively low demand and a constrained transmission network connecting them to other areas, hydrogen can play an important role in both securing a stable energy supply and increasing value-creation. Haeolus will thus provide operating strategies for wind-hydrogen plants but also for other relevant cases (isolated mini-grids, short and long-term energy storage, and hydrogen fuel production). In parallel, assessment analysis on the technology, the economy, the environmental impact and RCS requirements will be also produced throughout the project, with a world-wide scope and focus on relevant European regions, such as Norway, Denmark, northern Germany, Spain, Ireland and emerging wind-power markets such as Poland and Romania.

The Haeolus project aims to achieve TRL 7, i.e. demonstration in operational environment. It will cross the spectrum "from lab to market", bringing advanced control systems for electrolysers in wind farms into common usage, and providing a market-ready implementation by the end of the project. Dr. Robin ROCHE will be the PI of this project for the SHARPAC research team.

NEW ERASMUS + PROJECT: HYSCHOOLS

Hyschool is seeking to facilitate the future training needs of industry that are met in relation to hydrogen fuel cells and the wider hydrogen economy through existing knowledge delivered by Higher Education (HE) Institutions. The project's focus is helping schoolteachers to provide HE led knowledge available for all and enhance teacher training to allow currently little or misunderstood teaching of hydrogen to become more widely taught in school curricula at all levels. There will clearly be an impact on schools ultimately, but the initial most relevant priority will be on HE provision for student teachers, which will then filter down through the education system.

HySchools will enhance the quality and relevance of students' knowledge and skills initially through students studying to be teachers and beyond to the widest possible pool of students as the project concerns curriculum development. Bringing together and considering a wide range of industry sectors and subject areas to unearth new solutions and means of teaching the topic of Hydrogen Fuel Cell Technology (HFCT). Dr. Samir Jemei will be the PI of this project for the SHARPAC research team.

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THERMAL MODELLING AND EXPERIMENTAL COMPARISON FOR A MOVING PANTOGRAPH STRIP

BEST PAPER AWARD

INT. CONF. ON RAILWAY ENG., LONDON

ENERGY

The best paper award of the 19th Int. Conf. on RailwayEngineering has been delivered to FEMTO-ST researchersfor their work on thermal study of the catenary/ pantographinterface for a train in motion.

This paper describes a 2.5D complex model of the pantograph strip coupling between a 1D and a 2D model. Experimental and simulation results are presented and, by comparison,allow for validating the 2.5D model. Some physical phenomena are described and presented with the help of the model, such as the stagger motion thermal effect, particular heats and the effect of the material characteristics. Finally, the propose method enables to predict the critical thermal configuration during a train trip.

This work is based on collaboration between FEMTO-ST and SNCF R&D departments.

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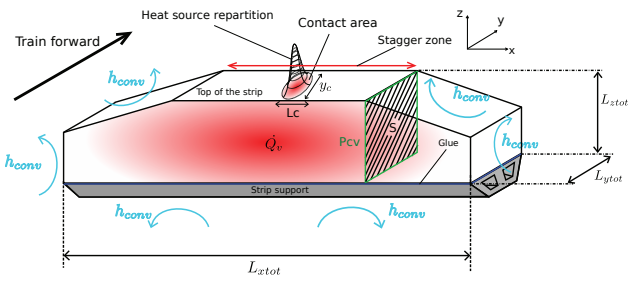

Pantograph strip description

MOLECULAR SELF-ASSEMBLIES ON SILICON SURFACE

MN2S

The adsorption of organic molecules on inorganic surfaces (see illustration) has been at the centre of varied and intense investigations. Such hybrid systems could serve as elements of electronic devices or sensors and enable the design of new nanomaterials and nano-drugs. A solid substrate is a very practical support for the organisation or reaction of molecules. The choice of the substrate will play on the molecule/ surface relation. For example, metallic surfaces are known to be poorly reactive with respect to molecules. Thus, it has been possible to create countless structures mainly thanks to intermolecular interactions. However, on semi-conductive surfaces, this interaction is no longer negligible and the formation of self-assembly of intact molecules is no longer obvious and has remained a challenge for a long time.

When the Nanoscience group started this activity, there was no example in the literature of extended molecular assembly on semiconductors despite their interest in molecular electronics. Starting from the boron-doped Silicon substrate, it is possible, by ultra-high-vacuum heating treatment, to obtain a reconstructed surface that is not very reactive with respect to molecules. From the choice of the molecule (size, symmetry and composition) will depend the molecule/molecule and molecule/surface interactions, and subsequently the structure and self-assembly obtained. Thus, for example we have succeeded, by using Scanning Tunneling Microscopy, in observing intact isolated molecules on silicon surface, also in forming unidimensional structures and finally in making 2D supramolecular assemblies. Moreover, thanks to a great deal of collaboration with theoreticians we have managed to better understand the interactions involved in these structures and thus establish corresponding models. The FEMTO-ST and IEMN teams have published a comprehensive review that provides an in-depth explanation of the basic concepts that have led to the many of these results.

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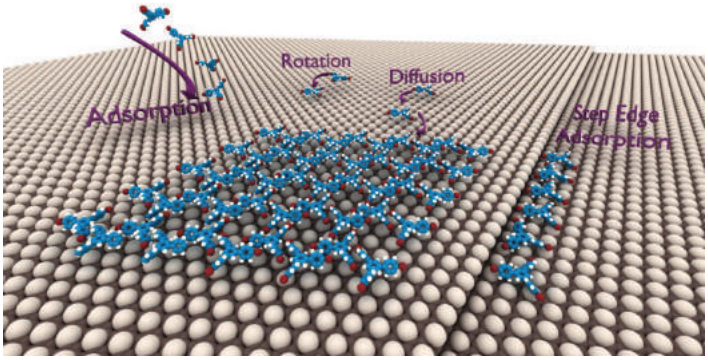

Example of some phenomena occurring at organic/inorganic interface

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HIGH-FREQUENCY SURFACE ACOUSTIC WAVE DEVICES BASED ON EPITAXIAL LINBO3 LAYERS ON SAPPHIRE

TF

The next generation of radiofrequency (RF) telecom applications urgently requires filters operating at high frequencies (around 5-6 GHz). A further increase in the frequency of conventional RF surface acoustic wave (SAW) filters, which are presently mainly fabricated from $LiNbO_3$ and $LiTaO_3$ single crystals, is limited by the period of interdigitated transducers and by the SAW phase velocity. So far the frequency of SAW devices has been limited to about 3.7 GHz. New low-loss materials with sufficiently high electro-mechanical coupling (K^2) and acoustic velocities are needed to achieve SAW filters at high frequencies. In CoSyMa team, we have studied the possibility to integrate deposited LiNbO3 films with SAW devices, in which high frequencies can be reached by excitation of guided dispersive acoustic waves.

The fabrication of high quality $LiNbO_3$ films is complicated by the difficulty to control Li^2O composition and consequently the composition and physical properties of the films. So far large scale production of films with physical properties suitable for the targeted applications has not been available. In the literature, SAW devices based on grown $LiNbO_3$ films present extremely high insertion losses (8-50 dB) and low K^2 (< 3 %). In our work, the ability to control Li composition was considerably improved and nearly stoichiometric LN films were deposited for the first time and in a reproducible manner by means of pulsed injection metalorganic vapor phase deposition. We have demonstrated an extremely high acoustical performance compatible with filter applications (insertion losses < 2 dB and K^2 = 8%) for SAW devices operating in the frequency range from 4.7 GHz up to 5.3 GHz and based on grown epitaxial Z-LN films on sapphire .

Extremely high velocities (10900 m/s) of lossy longitudinal SAW were also measured for the first time in $LiNbO_3$/sapphire structure (resonance at 11 GHz). These very promising first results permitted to create a strong relationship with two industrial partners, Annealsys for thin films synthesis and Qualcomm for RF filters.

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PERFORMANCES OF LGT PIEZOELECTRIC CRYSTALS

TF

Owing to its high acoustic quality, high piezoelectric coefficients and thermal stability, La3Ga5.5Ta0.5O14 (called Langatate or LGT) is a promising piezoelectric crystal for acoustic devices developed in the Time and Frequency domain, particularly for ultra-stable Bulk Acoustic Waves resonators and high temperature wireless sensors. However, these applications require homogenous material with reproducible and excellent properties, like quartz.

Indeed, during the crystal growth by Czochralski pulling process and the post-growth heat treatment, defects limiting the potential use of the crystal are created in the LGT ingot. These point defects can react as ionic and electronic charge carriers and generate conductive losses particularly at high temperatures. Consequently, the presence of point defects significantly affects the physical and chemical properties of the crystal.

We have used chemical, optical and/or electrical analytical methods to reveal and qualify these different defects. These methods are mainly:

- Femtosecond Laser Ablation

- ICP-MS or Glow Discharge Mass Spectrometry or Electron Probe Micro Analysis for the composition of the crystal,

- X-ray diffraction (DRX) to perform analyses of the crystalline structure of LGT samples,

- Measurements of the electrical resistivity on circular oriented thin discs,

- IR or UV-visible spectrometry on thick Y-cut wafer,

- Electron Spin Resonance (ESR) to detect paramagnetic centres and so colored ones

After intensive work (performed within M. Allani's PhD thesis), we have shown that the "boules" developed by Cristal Innov (in collaboration with Institut Lumière Matière (ILM), Lyon), lead to the growth of homogeneous LGT crystals up to 2 inches in diameter. In the FEMTO-ST Time and Frequency department, and then in RAKON (an industrial partner), we have investigated the potential of these LGT crystals to realize BAW and SAW resonators. We have demonstrated that LGT can give quality factors at the level of $1.3x10^6$ at 10 MHz, in a repeatable way, similar to those obtained with the best SC cut quartz resonators. It was also reported that the LGT produced by the Russian supplier those obtained with the best SC cut quartz resonators. It was also reported that the LGT produced by the Russian supplier FOMOS gives quality factors 4 to 5 times lower.

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OPTICAL FREQUENCY REFERENCES AND GENERATION OF ULTRA-PURE RADIO-FREQUENCY SIGNALS

TF

State of the art atomic clocks are based on optical frequency transitions to realise accurate time and frequency references. These clocks require the development of low phase noise and ultra-stable lasers (USL). Such lasers are also used for the generation of ultra-low phase noise signals in the radio-frequency (RF) domain, using optical frequency combs generated from femtosecond lasers.

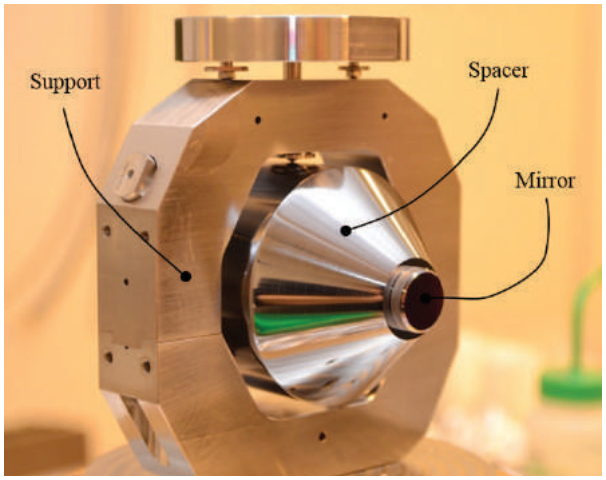
An USL is basically a continuous-wave laser locked onto a frequency reference. The latter is composed of a Fabry-Perot interferometer with two highly reflective mirrors that are optically contacted onto a spacer, in order to reduce frequency fluctuations of the cavity modes that scale with length fluctuations.

The geometry of the cavity is designed in order to minimise deformations induced by acoustic and seismic noise, yielding a sensitivity at the level of a few 10^{-11}/g. The cavities are made from ULE® glass or crystalline silicon and are operated at 290 K and 17 K, respectively. At those temperatures, the linear coefficient of thermal expansion is zero and the frequency drift is limited. The choice of materials also impacts the thermal noise of the cavity that scales with the inverse of the mechanical quality factor. For that reason, we use fused silica mirror substrates contacted on an ULE® spacer. The resulting limitation is a fractional frequency stability of 2×10^{-15} for a 25mm long cavity. For the 140mm long cryogenic silicon cavity, this limit is 4×10^{-17}.

The generation of low noise RF signals from our USL, using optical frequency combs, has allowed a frequency comparison with the signal at 10 GHz of a cryogenic sapphire oscillator developed in FEMTO-ST. The division of the optical frequency by a factor of about 20000 is ensured by stabilising the 250 MHz repetition rate of a femtosecond laser onto the USL. The RF signal extracted from the optical frequency comb by detecting the repetition rate and its harmonics with a fast photodiode is currently measured below -105 dBc/Hz at 1 Hz offset frequency. This is at least 30 dB lower than the best quartz oscillators.

More information

http://teams.femto-st.fr/equipe-ohms/



Picture of the optical frequency reference used to stabilize a laser: 140-mm long single crystal silicon Fabry-Perot cavity in its quasi-octagonal support.

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ULTRA-ACCURATE ROBOTIC ASSEMBLY FOR ELECTRO-PHOTONIC CIRCUITS

AS2M / OPTICS

The synergy between robotics and photonics at small scales is highly attractive from both scientific and industrial points of view. It notably opens up to a brand-new generation of original integrated photonic architectures but also to robot strategies demonstrating unprecedented capabilities.

From the photonic point of view, robotics enables to achieve active positioning tasks such as the optimisation of the transmission response as a function of the relative position of a disk resonator over an optical waveguide guide (see fig. below). The hybrid integration of individual photonic elements can also be performed through robotic assembly that cannot be obtained through clean room fabrication technologies. It notably enables to make the best choice of materials and technologies resulting in high yield, high product performances and opens to wide kinds of original photonic circuit architectures such as integrated lamellas for polarisation control, or 3D resonators for spectrometry or multimedia.

From the robotic point of view, photonics provides a sensory feedback through active alignment techniques and offers a unique way to better understand the behaviour of robots used for microscale tasks with high positioning accuracy performances. Original assembly strategies can then be investigated to reach high speed, high accuracy with high versatility.

Beyond these mutual interests, a generic methodology has been investigated that correlates optics and robotics behaviours through models. This original approach named photo-robotics enables to control the motions of components in the optical frame in a referenced way. First assemblies of a photonic lamella at the tip of an optical fibre have already demonstrated that an unprecedented accuracy (0.003° i.e. 50 µrad) can be obtained while the assembly lasts only 6 seconds in full automated mode from initial fully unknown initial position. This work is investigated through the CEPAGE project (ANR funding) and Nanorobotics projects (regional funding).

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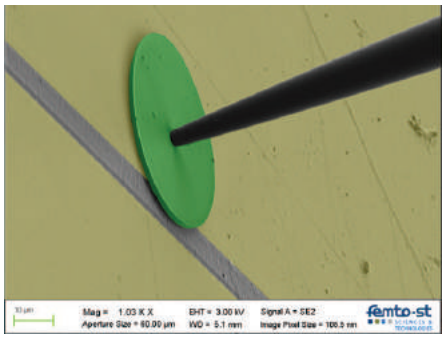

Scanning Electron Microscope image of the µdisk being aligned to a waveguide by a robotized tip.

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CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS (CMUTS) FOR INTEGRATED STRUCTURAL HEALTH MONITORING AND PROGNOSTICS OF COMPOSITE MATERIALS

APPLIED MECHANICS / AS2M

Evaluating the ageing process and damage tolerance of composite materials and assemblies is of paramount interest for increasing knowledge about the long term behaviour of future lightweight and highly resistant equipment for transport applications. The Acoustic Emission technique (AE) has been used for years for this purpose by material science's specialists in academia and industry. AE passively detects the sudden release of an amount of energy, accumulated during loading and liberated by a local fracture, in the form of an elastic wave which propagates from the damage to the surface. The induced subnanometric displacements are collected in real-time by permanently attached AE sensors and make this technique particularly relevant to Structural Health Monitoring (SHM) and prognostics. The use of AE requires solving two main problems: the design/choice of sensors dedicated to particular damages, the processing and interpretation of the massive amount of data collected during mechanical tests or in in-service conditions. The interpretation of AE signals originating from fatigue ageing of composite materials is still a critical issue for SHM.

Supported by the labex ACTION (Smart Skin research axis), a new integrative approach has been developed for AE-based SHM since 2014. The originality holds in the design and fabrication of networks of Capacitive Micromachined Ultrasonic Transducers (CMUTs) specifically dedicated to SHM of composite materials. The integrated approach that has been adopted for CMUT-based SHM aims at giving a hand in interpreting AE signals using specific skills in cleanroom technologies for MEMS design and fabrication, in mechanical simulation, in composite materials, and in dedicated machine learning algorithms for real-time data streaming analysis. The frequency selectivity and tiny size of the CMUTs will give access to new insights in composites' behaviour and will represent a breakthrough for SHM.

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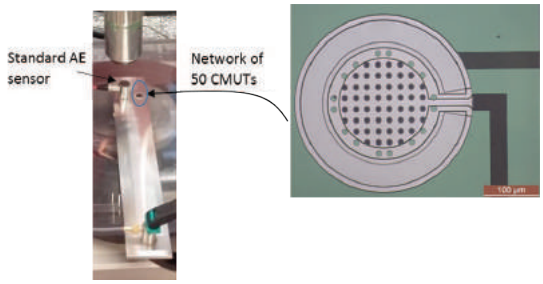

Left: A network of about 50 CMUTs installed on an aluminium plate; Right: A close-up of an individual CMUT.

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SOUND MODULATES LIGHT AT THE NANOSCALE

MN2S / OPTICS

Acousto-optical modulators modulate the intensity of light waves thanks to the interaction of sound and light. While such systems usually have the size of a matchbox, researchers from FEMTO-ST Institute have elaborated a theory to design them at the nanoscale.

In a classical acousto-optical modulator, acoustic waves generated inside a crystal create a diffraction grating. The grating compresses and dilates alternatively light that goes through the crystal, thus allowing for dynamical modulation. This effect, however, remains small compared to the volume occupied by the crystal and has to be accumulated along many periods of the acoustic wave. Therefore, the system size could not be reduced easily. In contrast researchers from the FEMTO-ST Institute have proposed a new model for nanoscale modulators, where interaction results from surface rather than from bulk effects.

In their system, the acoustic waves are shaking an array of slits that are about 200 nanometers wide and 300 nanometers high. Sitting on a piezoelectric lithium niobate substrate, the slits vibrate in the manner of a tuning fork and their shape is strongly modified. Light passing through the slits undergoes a resonance phenomenon that acutely depends on the slit shape. Thus, at an acoustic frequency of 0.5 GHz, the slits deform with a 30-nanometer amplitude and generate an 80% optical intensity modulation in the near infrared. This work could lead to the design of highly compact photonic devices. Nowadays acousto-optical components are found in satellite borne tunable spectrometers or in ultrashort laser pulse shaping systems.

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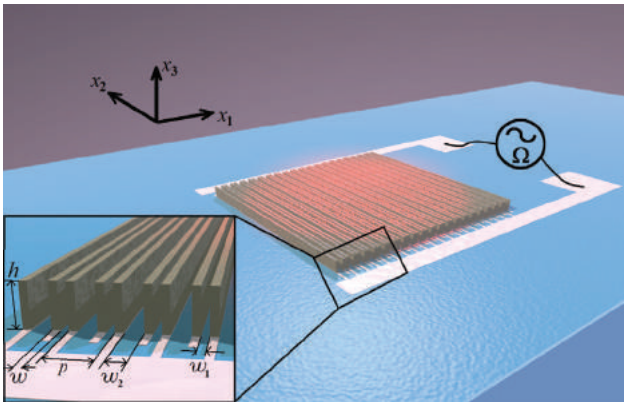

Schematic representation of the principle of the nanoscale acousto-optical modulator.

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QUANTUM INFORMATIONRMATION TEAM: QUBITS

MN2S / OPTICS

Do you speak QUBIT? If so, your words are quantum bits, they superimpose, entangle, convey your implicit thoughts, but need your mouth or your hand to be recorded.

Quantum information is such a language, closer to our human language than the Turing machine. If you speak QUBIT, your words are Ψ symbols, both particles and waves, both dead and living cats, inhabiting the whole universe at the same time but, at the end of the day, they need you to be contextualised to become real. Among many places in the world, QUBIT is spoken at Station Q (Microsoft Quantum), where the Fields medal winner Michael Freedman is leading the group on topological quantum computing (TQC). QUBITS are very sensitive to the environment. To avoid the need of expensive error correction schemes to fight against decoherence, TQC is a very promising solution.

There is work about quantum information that is developed at UBFC and supported under the UBFC project I-QUINS: integrated quantum informatio at the nanoscale. It comprises the following topics (i) Quantum algorithms and the geometry of quantum computation, (ii) Quantum control (iii) Integrated systems, and reflects the knowledge accumulated over the last years by members of UBFC in Besançon, Montbéliard and Dijon. Let us focus on two aspects developed at FEMTO ST.

One of them, quantum interferometry, is performed in the OPTICS Department. It consists of robust high-dimensional (N = 9) frequency-path quantum interferometry in long-haul optical fibres, in which twin-photons travel a distance up to 60 km.

Another one is QBism: quantum Bayesianism. This started with the Copenhagen interpretation and now QBism is relooked in terms of very symmetric and informationally complete generalized quantum measurements: SIC-POVMs. I found that one could remove the 'I' and built IC's that are intrinsically connected to permutation groups, universal quantum computing and three-manifolds: a promising way towards TQC.

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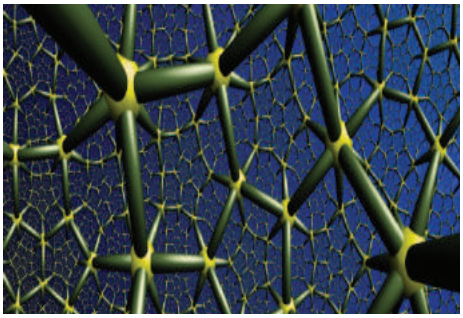

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SCIENTISTS ON SOCIAL SCIENCES AND HUMANITIES JOIN FEMTO-ST

Engineering Science and Social sciences have to work together to provide future innovative products which can be useful for Human. Indeed, technology makes sense only if it is designed and developed taking into account the human associated environment characterized by their cognitive, sensory and affective aspects. Moreover, technological objects also shape and transform the frames of human experience. Technology and Human interacting together is a complex and dynamic phenomenon, leading changes in mindsets, behaviours, economic and social models.

Some fruitful and effective collaboration between social and engineering sciences requires the excellence of social research, which can only be achieved by the double movement of deepening inside one discipline and interdisciplinary work.

The RECITS group composed of Social and Human Sciences researchers is a new transverse axis inside FEMTO-ST. The group describes the technological changes as dynamical social processes, shaped by the "frictions" between emerging technologies and society (institutions, organisations, territories, etc.). Their activities focus on the analysis and modelling of the production of knowledge, artifacts and technologies. This production is based on complex networks of actors structured by history, practices, modes of governance, public action, etc.

As an example, RESponSE project (see p.10, Interreg bialateral call Switzerland-France) provides an example of the activity of the RECITS group at FEMTO-ST. This project aims at building a network of sensors to enhance firefighter's safety during interventions. Setting this network raises technological as well as social and ethical issues: (i) privacy and health data usage, (ii) responsibility of Artificial Intelligence managing the network, (iii) transfer of current technical knowledge to predictive algorithms. RECITS is providing an exhaustive description of the technological and cultural environment of firefighters in order to build a network in accordance with the professional culture and needs.

More information

http://www.femto-st.fr/fr/Departements-de-recherche/AXES-TRANSVERSES/Recits/

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PRONOSTIC AND HEALTH MANAGEMENT OF FUELL CELLS

BEST THESIS AWARD IN AUTOMATIC CONTROL

AS2M / ENERGY

Marine JOUIN has been recognized with the biannual Club EEA award for best doctoral thesis in Automation. She received this prize as reward for a very well-achieved research work on Prognostics of Fuel Cell Systems. During her thesis, Marine JOUIN developed a hybrid prognostics approach based on electrochemical modelling and particle filters. This work has also been honoured by numerous international publications (including 6 journal papers) and a best-paper award (AMEST 2016 conference). All over again, it underlines the dynamic of a multidisciplinary program at FEMTO-ST (Prognostics of Fuel Cell Systems) that involves researchers from AS2M (PHM group) and ENERGY (SHARPAC group) departments.

Reference

Marine JOUIN, "Contribution au pronostic d'une pile à combustible du type PEMFC - approche par filtrage particulaire", defended on December, 10th 2015

This thesis has been supervised by Noureddine ZERHOUNI (dir.), Daniel HISSEL, Rafael GOURIVEAU and Marie-Cécile PERA.

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https://www.clubeea.org/index.php/prix-de-these/en-automatique

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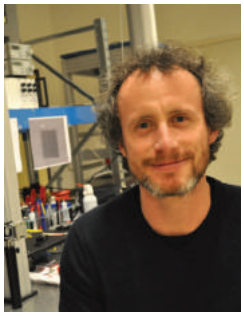
DANIEL BRUNNER: NEURAL NETWORKS AND PHOTONICS

OPTICS



Daniel Brunner joined the FEMTO-ST OPTICS department as a CNRS researcher in October 2016. He did his undergraduate studies at the KIT in Karlsruhe, Germany. In 2005, Daniel moved to the Heriot-Watt University in Edinburgh, Scotland, where he obtained his Master degree in 2006. Remaining in Scotland, he continued with a PhD in 2010 in coherent spectroscopy of single quantum dots. During that time, the coherence and relaxation of single hole spins in semiconductors was his main object of interest. After having experienced the world of quantum optics, D. Brunner became curious about other optical phenomena and started a postdoc position in the group of Prof. Ingo Fischer, IFISC, Palma de Mallorca, Spain. In the framework of the PHOCUS project from the EU call Future and Emerging Technology, he participated in establishing novel machine learning concepts in nonlinear optics. From 2011 until 2013 he held a Marie-Curie Intra European fellowship. Before moving to Besançon, he collaborated with other members of the OPTICS department from 2010 onwards.

His work revolves around fundamental aspects of nonlinear photonics and possible applications to Neural Networks. Currently, Neural Networks as computing machines experience a strong increase in attention. Nonetheless, they face fundamental challenges: their implementations are highly inefficient and they mainly remain mysterious black boxes. Photonics is a hot candidate to overcome the first limitation, while nonlinear dynamics are an essential asset to illuminate the black Neural Network box. As such, the interfacing of both fields is what drives him and his work.

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FEI GAO: FUEL CELLS MODELING

ENERGY

Fei Gao joined the FEMTO-ST Energy department in September 2016 firstly as associate professor in the field of electrical engineering and renewable energy. He received respectively, from the University of Technology of Belfort-Montbeliard (UTBM), the engineer degree (European Master) in electrical and control system engineering in 2007, and the PhD degree in renewable energy with distinguished Youth Doctor Award in 2010. He was an associate professor at UTBM between 2011 and 2017, and became a full professor at the same institution this year at 33 years old. He is associate editor of 2 IEEE Transactions and 2 other international journals, and member of organizing committee for more than 20 IEEE international conferences. In 2017 he is nominated as the Conferences/Workshops Committee Chair of IEEE Transportation Electrification Community (TEC), and elected as the Chair of the Technical Committee on Transportation Electrification (TCTE) of IEEE Industry Electronic Society (IES).

His current research activities are mainly focused on two fields:

1) entropic modeling of aging and degradation phenomena in fuel cells, and

2) specific simulation algorithm development for nanoseconds level real-time simulation of power electronics systems.

Hydrogen Proton Exchange Membrane (PEM) fuel cell is a promising technology for future transport applications. Nevertheless, the accurate prediction of PEM fuel cells ageing and degradations state is still a major challenge. Today most of the fuel cell ageing prediction models are using machine-learning techniques, which have major limitations in their fundamental methodologies, especially in term of their prediction reliability and application complexity. His current work is focused on the development and demonstration of a novel and promising approach for the hydrogen fuel cell reliability engineering by using a fundamental thermodynamic quantity: entropy. This research field, with the strong support of CNRS research federation FCLAB at Belfort, is currently blank at international level.

On the other research field, with the arrival of the new generation of high switching frequency (hundreds of MHz) power electronic devices, new challenges have been raised for their real-time simulation applications in the field of transportation electrification. Fei Gao's work in this field is focused on the development of a sub-250 nanoseconds time step real-time simulation algorithm based on FPGA technology for power electronic applications. Different from today's CPU based real-time simulation technology, the FPGA based real-time simulation can achieve much finer time sampling, but requires specific mathematical algorithm development. It is a research field that has received great attention and important industrial investment in the last 5 years. FEMTO-ST has since established extended research collaboration with all major industrial partners worldwide.

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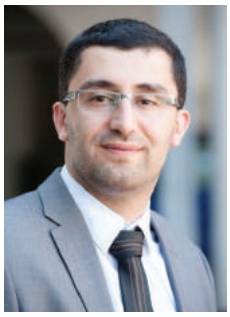
MUAMER KADIC: SURPRISING METAMATERIALS

MN2S



Dr. Muamer Kadic joined FEMTO-ST as an associate professor of electrical and electronic engineering in September 2016.
He is focusing on many fields of physics at once, with a preference for mechanics and electromagnetism. His ultimate goal is metamaterials. These artificial materials received their name from the Greek word “meta”, meaning “beyond”. They were first introduced in optics and in electromagnetism, and today many scientists are working on meta-objects. In collaboration with Tobias Frenzel and Martin Wegener (Karlsruhe Institute of Technology, Germany), Muamer recently published papers showing how one can obtain “extraordinary” properties with mechanicals materials, like twists. These materials exhibit richer behaviours such as mechanical activity (by analogy to optical activity). Such properties are not usually considered in continuum mechanics. In addition, another surprising effect was derived for the simple conductivity equation. Indeed, it was shown that the commonly used argument and the measurement method of the Hall voltage to determine the doping of a semiconductor could be wrong if the material is porous. The even less intuitive case of the ‘parallel Hall effect’, where materials show a Hall voltage along the direction of the magnetic field (appearing in the contradiction to the Lorentz force rule), was demonstrated and experimentally verified in collaboration with Christian Kern, Vitoria Schuster and Martin Wegener. This counter intuitive example was inspired from a mathematical theorem by Briane and Milton, and was later emphasised in a SIAM article. Eventually, all these results obtained in 2017 ended up as cover illustrations for Physics Today, SIAM, Physical Review Letters, and Science.
Muamer Kadic is thankful for the great help received from the Labex Action, who awarded him a most crucial starting grant and an invited professor grant for Graeme Milton (Utah Univ., USA). He also received decisive support from the Univ. Bourgogne Franche-Comté to work on metamaterials (ISite-BFC grant).

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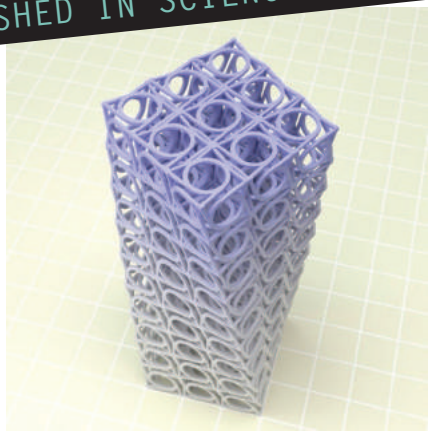
PUBLISHED IN SCIENCE / NOV 2017



A twist for metamaterials
Cover of Science / Nov.2017
A mechanical metamaterial that twists upon uniaxial compression. Image courtesy of Tobias Frenzel (KIT).

IEEE VPPC'2017

VEHICULAR POWER PROPULSION CONFERENCE

ENERGY

The 2017 IEEE 14th Vehicle Power and Propulsion Conference (VPPC) was held on 11-14 December 2017 in Belfort, France, under a shared organization between FEMTO ST CNRS Institute, FCLAB CNRS Research Federation, University of Franche-Comte and University of Technology Belfort-Montbéliard and IEEE Vehicular Technology Society.

The conference aims to provide a forum for sharing knowledge, experience and creative ideas in vehicle power and propulsion. VPPC'2017 has featured 350 participants, 220 peer-reviewed high-quality papers, 8 special sessions, 5 tutorials, 6 world-class keynotes. Regular tracks have been devoted to "Energy storage and Generation, Components and Systems", "Power Electronics, Motor Drives and Electric Power Systems", "Vehicular Electronics and Intelligent Transportation Systems", "Control and Energy Management of Transportation Systems", "Modelling, Analysis and Simulation of Transportation Systems", "Charging Systems and Infrastructures", "Hydrogen refuelling infrastructures and Fuel Cell Vehicles". The program has also feature conference-long industrial exhibitions and demonstrations. Moreover, a workshop associated to an EU-funded project, devoted to fuel cell buses (GiantLeap project), has been held in parallel of the conference.

The conference is proud to have had the support from strong companies, ALSTOM and SONCEBOZ, from the "Future Vehicle" industrial cluster and the MEGEVH French network on hybrid electrical vehicles, as well as exhibits proposed by DSpace, CRITT M2A, Rohde & Schwarz, OPAL-RT, Typhoon HIL, Imperix, Elecsys and H2SYS.

VPPC 2017 has been organized in a carbon care philosophy. Indeed, the CO2 emissions associated with the travel of attendees will be compensated by funding carbon reduction projects, locally or internationally.

More information

http://www.vppc2017.org

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JOINT CONFERENCE EFTF/IFCS

TF

The Joint Conference European Frequency and Time Forum & IEEE International Frequency Control Symposium was organized July 9-13 2017 in Besançon's Micropolis Conference Centre by the Société Française de Chronométrie et des Microtechniquesand strongly supported by FEMTO-ST. The two Co-General Chairs were Bernard Dulmet (FEMTO ST Time-Frequency) and Lute Maleki (OEWaves Inc.), and the Scientific Co-Chairs were Elisabeth Donley (NIST) and Jérôme Delporte (CNES). IFCS and EFTF conferences have been held every year since 1947 and 1984 respectively. Joint Conferences EFTF/IFCS started in Besançon in 1999 and rapidly became major events in the worldwide Time and Frequency community. They occur every two years since 2009 venue, also held in Besançon.

2017 Conference Topics included 6 groups:

1. Material, Filters and Resonators

2. Oscillators, Synthesizers, Noise and Circuit Techniques

3. Microwave Frequency Standards

4. Sensors and Transducers

5. Timekeeping, Time and Frequency Transfer, GNSS applications

6. Optical Frequency Standards and Applications

Tutorials included 3 tracks: Timekeeping and Noise, Atomic clocks and optical clocks, MEMS-NEMS.

Three plenary speakers presented outstanding talks: Virginie van Wassenhove (CEA, How does the human brain make sense of time?), Terry Quinn (Emeritus Director of BIPM, History of Atomic Time and the new SI), Lawrence Krauss (Arizona State Univ., Journey to the beginning of time). Technical sessions offered 154 lecture presentations in 4 parallel tracks, while 2 poster sessions and a student paper competition offered 246 posters presentations. 31 exhibitors presented their products. Rodolphe Boudot (Time-Frequency) and Vincent Laude (MN2S) were among the 21 Invited speakers.

The conference gathered a broad attendance of 558 persons from worldwide origin. For the first time in the history of joint EFTF/IFCS Conferences, Chinese attendance occupied the third rank after France and USA.

More information

http://www.eftf-ifcs2017.org/

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FRONTIERS IN PHOTONICS AND OPTICS EDUCATION

OPTICS

As part of an annual series of optics seminars welcoming high-level international speakers to FEMTO-ST, the OPTICS department held a Symposium on the topic of "Frontiers in Photonics and Optics Education" which took place on Wednesday 7 December, 2016.

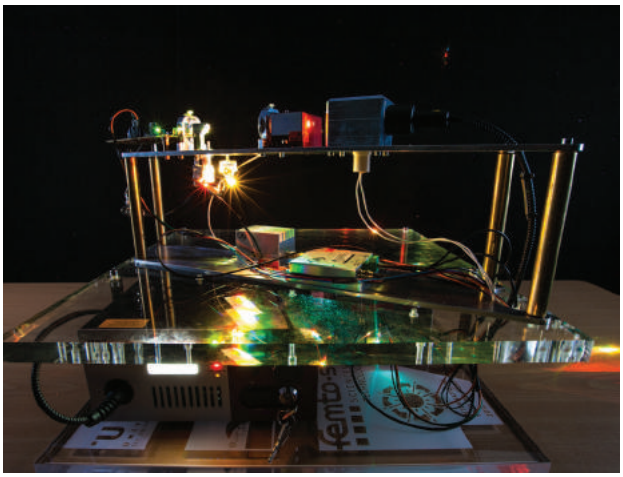
Three very distinguished speakers were invited to give a talk for this event:

• Gérard Mourou (Ecole Polytechnique, Palaiseau, France), gave a seminar on the topic "route to single cycle exawatt for pulse - laser subatomic physics". He is Professor at the Ecole Polytechnique and Director of the Institut de la Lumière Extrême at ENSTA. He has made numerous important contributions in the field of ultrafast lasers, high-speed electronics as well as in medicine where he introduced the field femtosecond ophthalmology. However his most important one is certainly the invention of the laser amplification technique universally used today and known as Chirped Pulse Amplification (CPA).

• Miguel Alonso (Univ. of Rochester, USA), the title of the seminar was "two sides of the Poincaré sphere in optics: polarization and beam structure." He was first associate editor and then deputy editor for optics express from 2002 to 2013. He is now associate editor for Optica. He is a fellow of the Optical Society of America.

• Joe Niemela (UNESCO-ICTP, Trieste, Italy), the talk dealt with "global education outreach using optics and photonics". Providing science teachers in developing countries with more effective strategies for engaging their students is the motivation for the UNESCO "Active Learning in Optics and Photonics" (ALOP) program. He is member of the scientific staff of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, a Category I UNESCO Institute.

This event gathered around one hundred participants from the FEMTO-ST institute, as well as undergraduate and graduate students. A lab tour was also organized during the afternoon.



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NATIONAL DAYS OF THE RESEARCH IN ROBOTICS

AS2M

The JNRR event is an unmissable meeting of the French robotics community (industrial and academic actors). The robotics days have been organised every two years since 1997. The JNRR'17 has celebrated its 20th anniversary with its 11th edition. It is a privileged moment of scientific exchanges around the numerous disciplines of robotics (design, modelling, control, perception, AI, education, etc.). The tradition is that at each edition two robotics labs join forces for the organization.

The JNRR'17 were organised by Inria-Bordeaux and FEMTO ST Institute in Biarritz from 8th to 10th November, 2017. The general chairs were David Daney (Inria) and Nicolas Andreff (FEMTO-ST) helped by both the program and the organization committees.

Thanks to a well-tailored organisation, and a dense, rich and varied scientific program, ranging from molecular motors to agricultural robotics, navigation problems to those of social robotics, through the ethics of research into robotics and education, nothing was left out and JNRR'17 was a great success. In fact, the 11th edition welcomed no less than 205 participants (all French robotics labs were represented), which constitutes a record since the creation of the JNRR events. The full program was structured around 35 scientific presentations mixing industrial and academic speakers internationally recognised in their respective fields. The traditional spirit of the JNRR events is to make an inventory (scientific, industrial and societal) of the French Robotics and underline its place in the worldwide community.

The JNRR'17 event was preceded, as is the tradition, by the "The Day of the Young Researchers in Robotics" (La Journée des Jeunes Chercheurs en Robotique – JJCR'17) held at the Technocité de Bayonne (November, 6th). The JJCR which is usually organised by PhD students in robotics (with the support of the JJNR organisation committee) was also a great success (about 60 participants).

The JNRR'17 was widely covered by the local and national media (radios and newspapers). The 2019 edition will be organised by the CITI Lab (Lyon) and Inria-LORIA (Nancy).

More information

https://jnrr2017.sciencesconf.org/

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INTERNATIONAL WORKSHOP SURFOCAP'17

MN2S

The 3rd edition of the International Workshop on functionalised Surfaces and their Applications to chemical and bio-sensors "SURFOCAP'17" was held in FEMTO-ST (May 30th – 31st 2017).

This Workshop was the opportunity to gather Scientists, Post-Doc students and PhD students around a topical theme dedicated to functionalised and/or nanostructured surfaces and their applications in the field of the development of micro devices such as chemical, biochemical and physico-chemical sensors. This meeting between scientists contributed to strengthen existing relations between the international scientific teams and to initiate future collaborative research projects.

SURFOCAP'17 gathered more than sixty scientists coming from Spain, Italy, Switzerland and France. This event featured the intervention of renowned scientists in the field of chemical and biochemical sensors. Indeed, four international invited speakers addressed plenary sessions related to chemical and biochemical sensors topics or the synthesis of nanostructured and functionalized surfaces:

- Professor Giorgio SBERVEGLIERI - University of Brescia (Italy): Fonctionnalization of metal oxide NWs for chemical sensors and electronic noses.

- Professor Andreas HIERLEMANN - University of Zurich (Switzerland): CMOS-based monolithic micro-electrode systems for sub cellular-resolution electrophysiology and sensor applications.

- Professor Alberto PALMERO - University of Sevilla (Spain): Fundamentals and Applications of Highly Porous Coatings grown by Vacuum and Plasma-Assisted Techniques at Oblique Angles.

- Professor F. Javier DEL CAMPO - University of Barcelona (Spain): Self powered biosensors and the role of electro- chromic materials.

This meeting also included 17 oral communications as well as 15 poster presentations during special sessions. Finally, several papers were selected and proposed for publication in Materials Today Proceedings.

More information

http://events.femto-st.fr/surfocap-2017

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SECOND WOMBAT MEETING

OPTICS

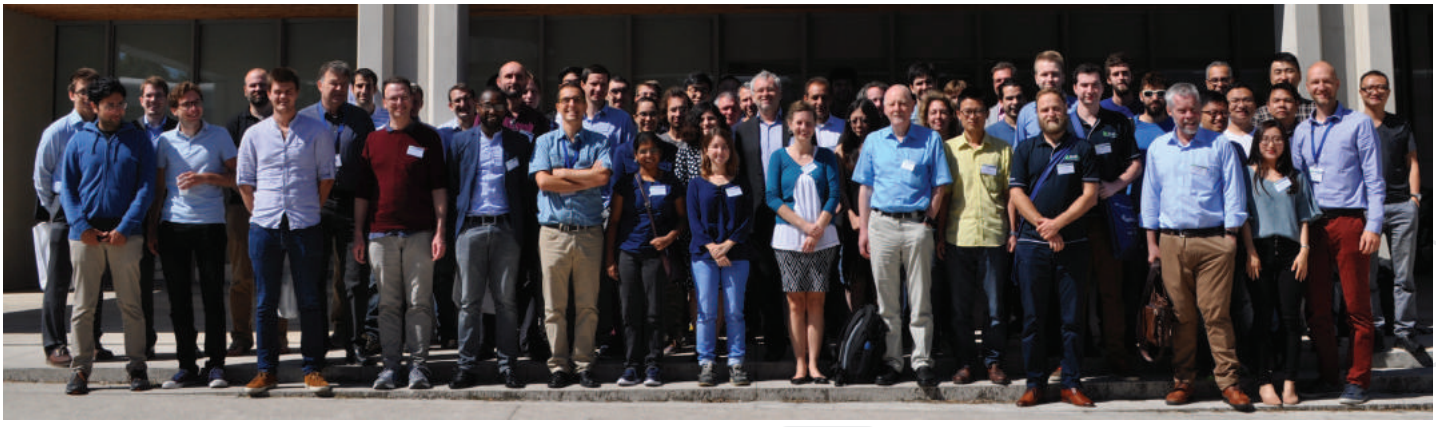
After the great success of the first workshop in Sydney in 2015, the second WOMBAT (Workshop on OptoMechanics and Brillouin scattering, fundamentals, Applications and Technologies) meeting was organised by FEMTO-ST in Besançon on 3-5 July 2017.

It brought together European and other international researchers in the field of physics and applications of opto-mechanics and Brillouin light scattering. The symposium celebrated the fact that it will be soon 100 years that the theory of light scattering in transparent materials was introduced by Brillouin in 1922. We have assembled a fantastic program of speakers who have explored the many ways in which Brillouin scattering and optomechanics play an essential role in photonics.

For 3 days, 90 researchers from 11 different countries (France, Israel, Brazil, India, China, Austria, Australia, Swiss, Germany, Spain, USA) presented recent results in a pleasant environment.

More information

http://events.femto-st.fr/WOMBAT-2017



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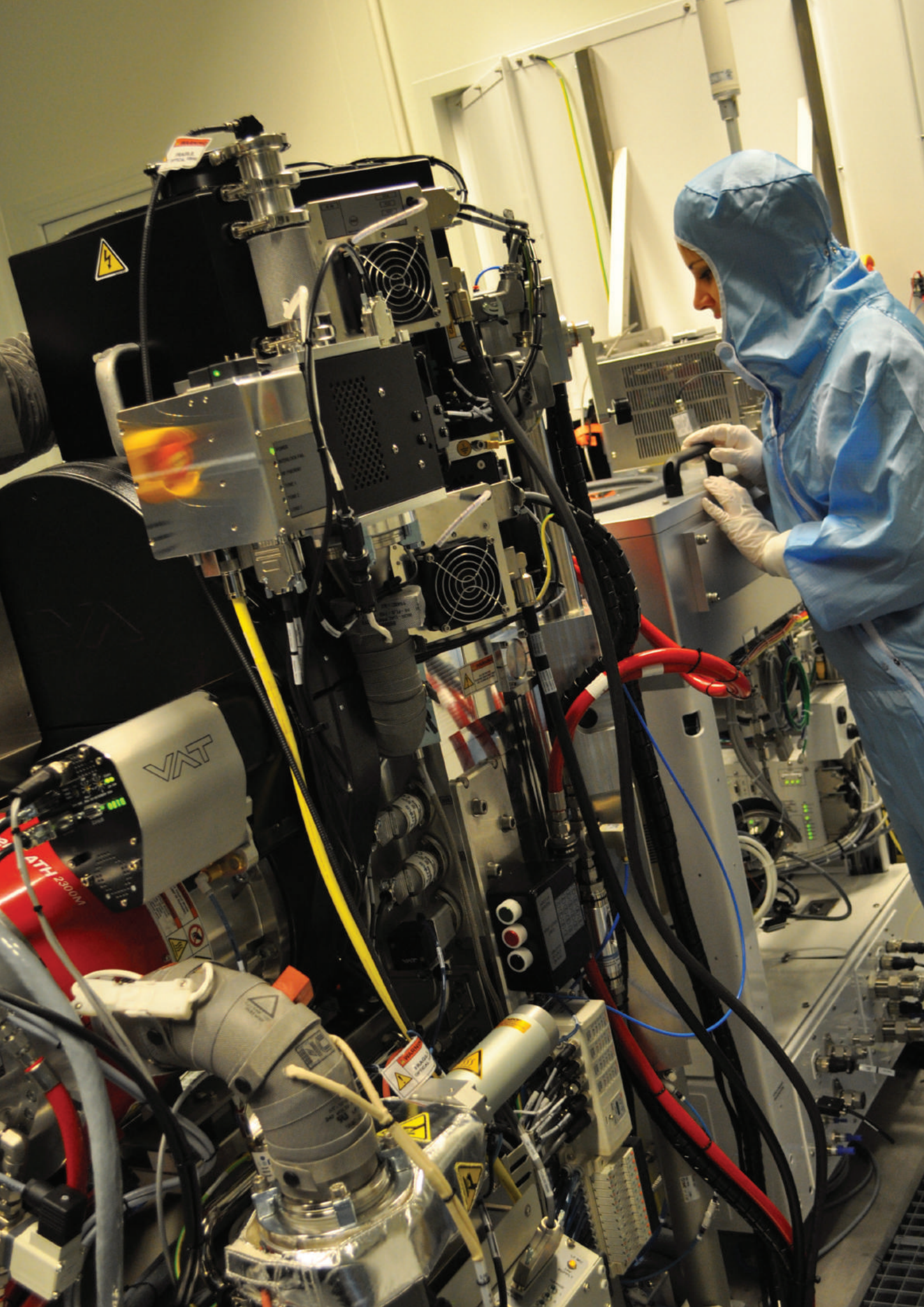
VAT

ANANKÉ

COMBINED HEAT AND POWER (CHP)

ENERGY

Ananké is the name of a Greek primordial deitie who personifies inevitability, compulsion and necessity. Ananké is also a company which works on fatal heat recovery using External Heat Supply Engine. Any heat flux, such as fumes from an industrial process, an engine (heat dissipation or exhaust heat), a boiler or any other equipment that generates heat, and whose temperature is at least 150°C, can be efficiently upgraded by converting it into mechanical and / or electrical energy and useful heat. The energy thus produced can be consumed directly or injected into electricity grid.

The good performance of the technology is based on scientific knowledge and important know-how. The team has been working on this technology since 2010 and has acquired solid skills, particularly through research and prototype work, needed to launch the production of a first Ericsson-type engine.

The Ericsson engine is an External Heat Supply Engine, also known as an external combustion engine or a former name for a hot air engine. Its first use dates from the nineteenth century for a naval propulsion application, or in small industries like in printing-house.

This thermal machine operates between two external heat sources via exchangers. It uses valves to control the flow of working fluid between two chambers, one of compression and the other of expansion.

Offering higher theoretical performance than the Stirling engine, the new technology bricks of the 21st century generates a renewed interest in simplifying its realisation.

These applications associated with the energy transition are numerous, thanks to its capacity to valorise the thermal discharges to convert them into a mechanical movement, and thus to produce electricity.

The innovation of our product relates to its capacity to modify stroke volume according to the load or the thermal power available. In addition, this Ericsson motor uses metal bellows instead of piston-cylinder assemblies present in "traditional" engines. In addition to the advantages of lower mechanical losses and leaks, this new concept eliminates any lubrication system and allows the internal volumes to be varied online while maintaining the possibility of easily modifying the thermodynamic cycle. The engine yields are high and reduce the price per kilowatt installed.

More information

http://ananke.company/

https://www.entreprises.gouv.fr/files/cp-laureats-gpni-2015.pdf

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H2SYS

FUELL CELL SYSTEM

ENERGY / FEMTO Engineering

After nearly three years of financial support within FEMTO Engineering to achieve technological maturity, H2SYS was established in September 2017, ending in this way the SATT funding in November.

The company, which specialises in the development of fuel cell systems and electric hydrogen generators, has received its first orders and is pursuing its technical developments in partnership with the FCLAB CNRS 3539 research federation.

The growth of the hydrogen sector, at national and international level, allows H2SYS to position itself in different industrial projects and to offer parallel products adapted for academic research activities.

Currently 5 people are working full time on the project. Several recruitments are ongoing to strengthen the business and put on the market the various developed solutions.

The success of the start-up, which hopes to achieve a turnover of more than 500 000 € for its first year, is partially due to the support of regional organisations that have significantly helped to develop the technology and to promote its innovations for a year and a half.

Successive organizations have thus participated in the construction and success of the project, starting with the University of Franche-Comté, then the UBFC, the SATT, GE, FEMTO-ST and the CNRS.

H2SYS is autonomous but continues to maintain links with the various structures by participating in research projects and contributing to the regional economic development.

More information

https://www.h2sys.fr

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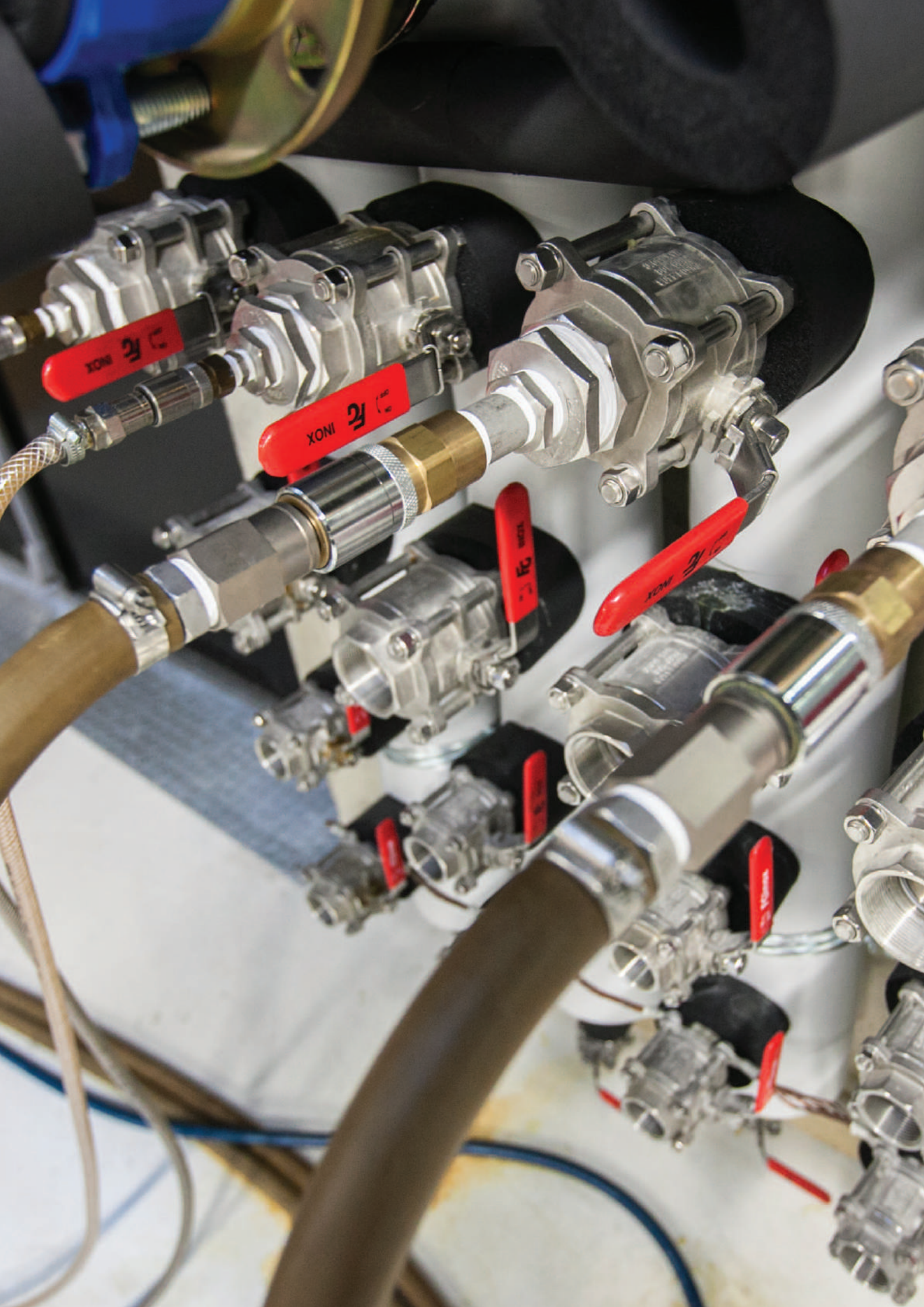

XONI

VERSO OPTIM

SOFTWARE FOR OPTIMAL PLANIFICATION

AS2M

Founded in December 2017 by FEMTO-ST members J. Coupey, J-M. Nicod and C. Varnier, the spin-off VERSO Optim proposes efficient optimization software tailored to solve planning and optimization problems in industrial contexts.

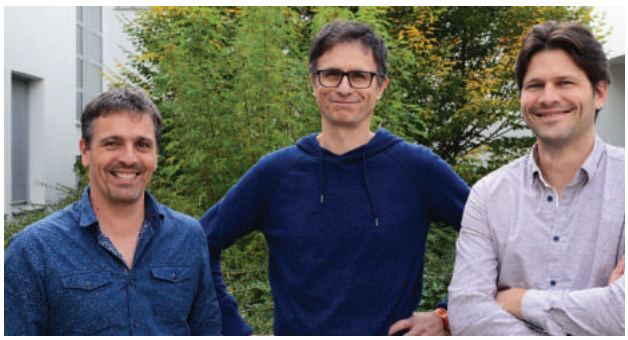
Many companies from different fields (logistics, transport, supply-chain, manufacturing) face planning and optimization problems arising in their workflow. A widely-spread response is to use human expertise and "common sense" to get practical solutions. The resulting process is usually very time-consuming (hours), it offers no flexibility and yields largely sub-optimal solutions. VERSO Optim proposes innovative software, implementing efficient and fast algorithms based on up-to-date research results from FEMTO-ST. Solving specific problems in real-life practical applications is then a matter of seconds.

VERSO Optim has a specific expertise in the field of vehicle routing problems (VRP) encountered in logistics and mobility. Production-ready software has been tested on use-cases in that domain, resulting in a drastic reduction of planning time and an overall simplification of the workflow. Switching from human-based planning to an artificial intelligence enables to reduce the planning time from a few hours to a few seconds. Solutions are also better with gains from reduced travel times, distances and gas emissions usually beyond 20%.

Other markets will be addressed in the next years, including supply-chain and manufacturing. The company is already setting partnerships with field players in France and abroad.

More information

https://www.verso-optim.com



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KIPERS INDUSTRIES

PROGNOSTICS AND HEALTH MANAGEMENT

AS2M

Funded in November 2017 by two researchers from FEMTO-ST Institute (Rafael Gouriveau and Marine Jouin), Kipers Industries commercializes a Prognostics and Health Management (PHM) software suite that enables enhancing availability of industrial systems, ensuring quality of services, while reducing exploitation costs (maintenance, scrap, delay...). The solution relies on transforming a set of raw data gathered on the monitored equipment (vibration, temperature, loads...) into one or more health indicators. A prognostics module makes it possible to track and predict the behaviour of the equipment, and thereby, to define reaction strategies that are appropriate and circumstantial (decision-making aids: optimized control, predictive maintenance).

Scientific backgrounds of Kipers Industries solution are issued from work led at FEMTO-ST Institute, such as the development of evolving prognostics algorithms based on Extreme Learning Machine or Particle Filters. Besides Kipers Industries and FEMTO-ST still collaborate in research programs that not only focus on relevant scientific bottlenecks, but also prefigure new business opportunities. In other words, both partners are looking for mutual interests in developing innovative solutions to be brought to industries.

More information

http://www.kipers-industries.com/

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A GROWING PARTNERSHIP WITH GROUPE PSA (PEUGEOT-CITROËN)

ENERGY / DISC / AS2M

In 2016 PSA Group, FEMTO-ST Institute and Bourgogne Franche Comté Region launched an industry university partnership in order to promote and support close collaboration between academic and industrial research activities. In 2017 several joint projects ran between FEMTO-ST and PSA Group in key research areas: energy conversion, smart systems, sustainable mobility and internet of things.

- Stirling Engine used as an Auxiliary Power Unit in a Series Hybrid Vehicle: Internal combustion engines waste a large portion of the available fuel energy as heat loss via exhaust gas and most of car engines operate with an efficiency rate of about 30%. Nowadays, the need for alternative propulsion systems with substantially improved fuel economy and adaptability to various fuels contributes to the development of technologies like the Stirling engine. This project co-developed by FEMTO ST and FEMTO Engineering concerns the development of a Stirling engine used as an Auxiliary Power Unit in a Series Hybrid Vehicle.

- Electrical wiring harness in a vehicle: the aim is to study the effect of the wire environment within the vehicle and within the strand (interlacing, heating of the nearby wires, ageing) and its impact on the electrothermal dimensioning of the wires.

- Programmable Matter: the ability to change the shape of an object has many usages in car manufacturing. Together with PSA Group, we are investigating the possibilities of fabricating a programmable matter composed of small micro-robots. These micro-robots are all linked together and can turn around each other to change the shape of the object. Linked with some Computer Aided Design software, it can speed up the design of new parts by offering a real interaction between the virtual and the real object. Both objects are able to modify the properties of the other. We are also studying the possibility of sculpting a shape-memory polymer to allow rapid molding process.

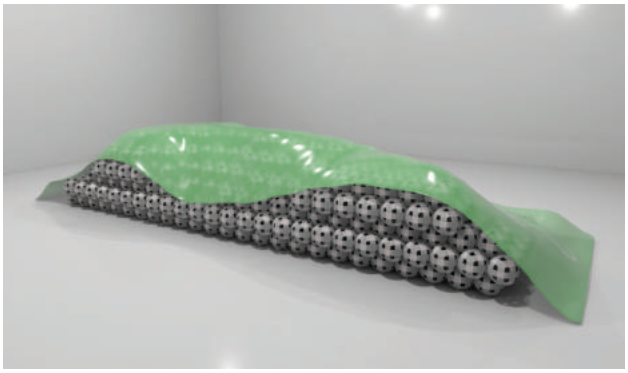

Illustration of a collection of microrobots and a shape-memory polymer.

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AFULUDINE START-UP RECEIVES THE PIERRE POTIER AWARD ON SUSTAINABLE DEVELOPMENT

APPLIED MECHANICS

Through fruitful collaboration between different academic and industrial research entities (FEMTO-ST Institute, UTINAM Institute, APERAM Research center and Isbergues), a new green lubricant solution AFULudine has been developed for stamping operations in substitution to the usual mineral oils. The main idea is to combine different essential requirements such as a low environmental impact and ease-of-use according to the market needs and the more and more restrictive environmental legislation (e.g. REACH). Based on the Self-Assembled-Monolayer (SAM) principle and so on a perfect control of the chemical reaction between the solution and the substrate (grafting of molecules onto the surface), AFULudine offers an efficient technical answer for improving stamping processes.

First studies showed the effectiveness of synthesised organic molecules by AFULudine to improve friction behaviour of different metallic substrates (Cu, Ti, Stainless steels...). Most recently studies go further into the industrialisation of the concept of the Self-Assembled-Monolayer through the AFULudine solution by providing results obtained on both laboratory and industrial presses.

With a lower friction coefficient and/or force applied for carrying out stamped parts compared to other lubricant solutions, AFULudine appeared to be relevant to offer an alternative to mineral oils and more especially to the chlorinated ones that highlight better performances than most non-chlorinated lubricants. For once, a more eco-friendly lubricant solution is conceivable. This new lubricant has already been integrated in industrial production line in some 30 French and Swiss stamping and blanking companies since 2017. Indeed, AFULudine is very well-adapted to mass production of large series cut and stamped stainless steel parts.

Historically, the tripartite collaboration started in 2013. Then AFULudine became an incubed company supported by the Franche-Comté University. In 2015 it was awarded the first prize both I-Lab and French-Tech competitions. The company was created in September 2016 and has been rewarded first prize both I-Lab and Company&Environment this year again. In 2017 AFULudine has received the Pierre Potier award which is the national award of innovation in green chemistry.

More information

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COMMON LABORATORY WITH GORGY TIMING: FAST LAB

TF / DISC

The FAST-LAB, common laboratory project, aims at promoting and shaping the interest of FEMTO-ST, OSU THETA and the company Gorgy Timing for developing secure and certified time dissemination systems. Time dissemination has become a requirement for current interactions in a society meeting increased timing pressure in its exchanges. Improving accuracy, traceability and safety has become mandatory for the time references clocking today's rail and air traffic, or in the context of distributed energy production in the context of smart grids. Similarly, we address secure timestamping financial transactions - with Europe being the first institution to draft a law governing such activities with a time reference (MIFID2) - as well as synchronising distributed power generation and high bandwidth communication networks. In these 3 examples, the core information is "time" and, within the current deployment framework, security and tracking the timestamp information is only beginning.

The broad range of time sources, including historical Very Low Frequency (VLF) sources which are currently neglected considering the ease of use of Global Navigation Satellite System (GNSS) networks, provides means of reducing jamming and spoofing risks. Safety of these critical timing services has become a need that we address by securing the timestamp exchange (using cryptography and two-way interactions between clocks exchanging messages). Making the best use of the sources of time and means of accessing these time representations are on the one hand addressed by combining multiple commercially available sources (GNSS, quartz oscillators) and on the other hand by developing dedicated systems meeting the unique requirements of redundancy (flexible software defined radio receivers able to adapt to jamming sources, composite sources dedicated to time transfer applications, time transfer over optical fibers such as White Rabbit).

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CRYOGENIC SAPPHIRE OSCILLATOR: TOWARD A COMMERCIAL PRODUCT

TF / FEMTO Engineering

Research on cryogenic sapphire oscillators (CSO) started in our lab in 1995. The CSO development has been successively supported by the space French agency (CNES), the Délégation Générale à l'Armement (DGA), the Laboratoire National de Métrologie et d'Essais (LNME) and the Région Bourgogne Franche-Comté. The project ELISA, funded by European Space Agency (ESA), represents the outcome of all these efforts: the objective set by ESA was completely fulfilled and we demonstrated for the first time the possibility to use a cryocooler while maintaining state-of-the-art frequency stability. With an exceptional fractional frequency stability, CSO allow the operation of laser-cooled microwave atomic clocks at their quantum limit. They provide the means to improve the resolution of space vehicle ranging and Doppler tracking provided by deep-space networks, as well as the resolution of very long baseline interferometry (VLBI) observatories. CSO can also enhance the calibration capability of metrological institutes or help qualify high performance clocks and oscillators. We were conscious that there was a niche market for CSO so in 2011 we initiated a voluntary economical valuation project codenamed ULISS: a new CSO was specially designed to be transported by road and it actually travelled more than 10,000 km around Europe to be tested at various laboratories and industrial companies. The objective was to demonstrate, on potential user's sites, the performance of this new technology and to better understand the needs of each specific application. Eventually, the ULISS-2G project (ANR Emergence) allowed to significantly increase the level of technology readiness level (TRL) of our technology, making the CSO ready for commercialisation.

In June 2017, FEMTO-Engineering started building three cryogenic sapphire oscillators for an international customer demonstrating the know-how of FEMTO-ST. The first CSO is expected for delivery in early 2018. Some other customers are also foreseen and the business will surely grow in 2018.

2 CSO in operation on platform OSCILLATOR-IMP

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FEMTO-ST MINIATURE ATOMIC CLOCKS IS READY TO BE AN INDUSTRIAL PRODUCT

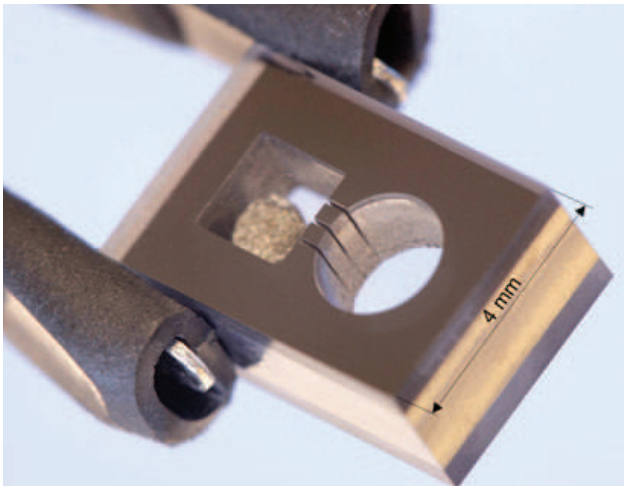
MN2S / TF

After almost 8 years of research activities on miniaturisation of atomic clocks by two departments of FEMTO-ST (TF and MN2S), competencies and expertise have been transferred to two French SMEs under the supervision of DGA in the frame of a RAPID project. A consortium (Tronics microsystems, Syrlinks and FEMTO-ST) has been created in order to provide a French commercial version of a miniaturised atomic clock. Miniature atomic clocks provide long term stabilities that quartz frequency references cannot achieve. Moreover, their volume may reach only 15 cm^3. Such clock is based on coherent population trapping phenomenon allowing to probe microwave atomic transition of Cesium atoms by optical means. To do so, the light emitted by a modulated VCSEL (Vertical-cavity surface-emitting laser) diode illuminates a Cesium vapour cell made of silicon and glass, generated by microfabrication processes. The cells are filled by a method developed at FEMTO-ST which consists in laser activation of Cesium dispensers located in the sealed cells. One of the partners, Tronics Microsystems, is now able to produce 350 cells per 6-inch wafer with an encouraging yield of almost 80%. First physics packages including the laser diode, optics, photodiode, thermal regulation, magnetic coils and shielding, designed in FEMTO-ST and fabricated by Tronics are currently under test in FEMTO-ST. The measured clock fractional frequency stability is close to $1x10^{-11}$ at 1 day integration time, i.e. close to 1 µs per day in laboratory environment. The goal is now to maintain such performances in harsher conditions, where temperature can vary in a wide spectrum operating range with an effective cost and little power requirement. For this purpose, optimisation of the control electronics is in progress in Syrlinks company. All these developments are pursued in the framework of a new DGA project (Direction Générale de l'Armement) led by Tronics Microsystems and for which FEMTO-ST is now a sub-contractor. Meanwhile, research activities are still on at the institute concerning improved CPT clocks as well as next-generation miniature quantum clocks.

More information

http://teams.femto-st.fr/equipe-ohms

http://projects.femto-st.fr/MOEMS-Group



Single Cesium vapor cell fabricated at Tronics Microsystems.

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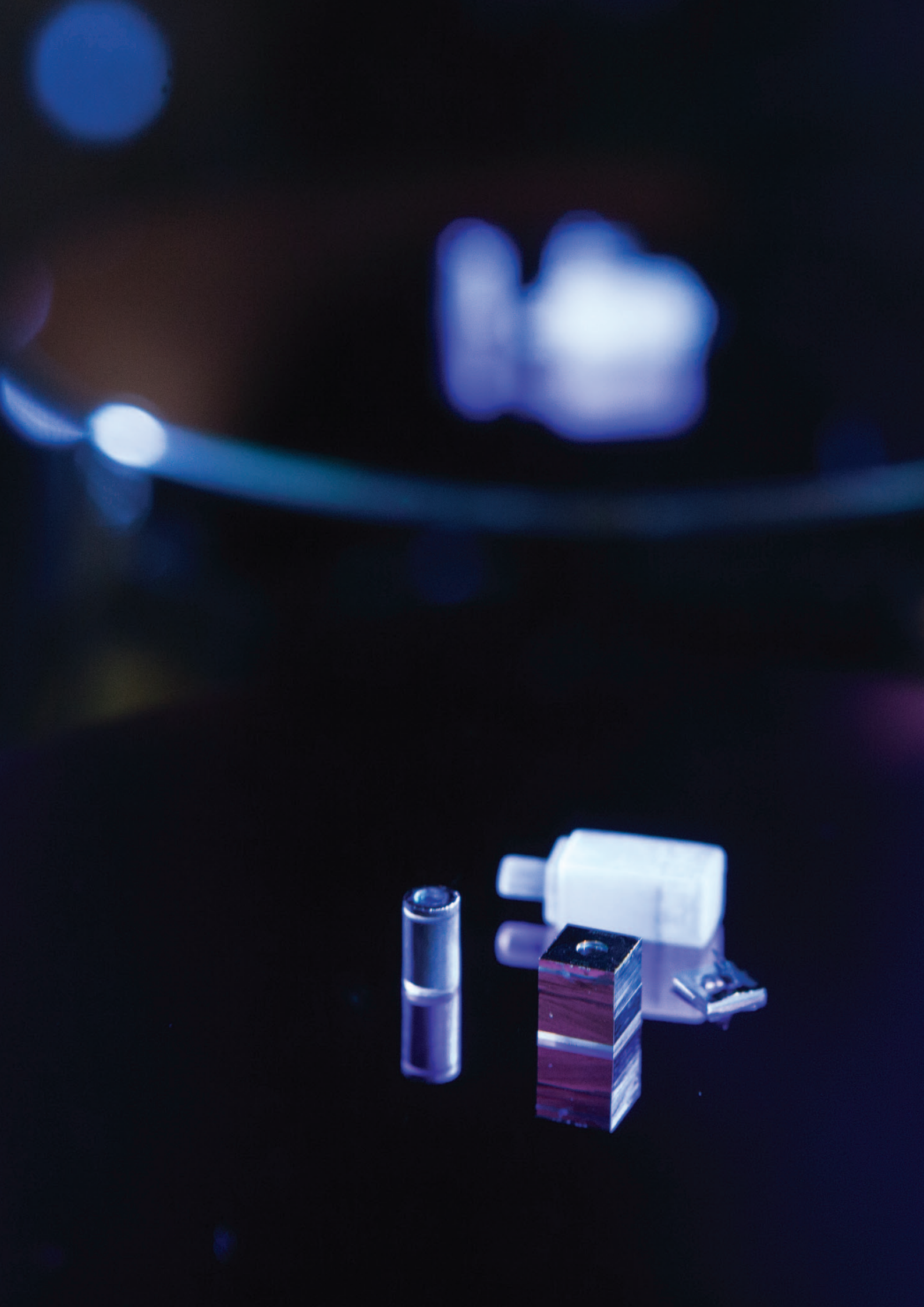

FEMTO-ST IN FIGURES

750 STAFF

7 RESEARCH DEPARTMENTS

1 MICRO-NANO TECHNOLOGIE CENTER

1 CENTRE FOR TECHNOLOGICAL DEVELOPMENTS

MORE THAN **100** WORLDWIDE INSTITUTIONAL ACADEMIC PARTNERS

39 M€ ANNUAL BUDGET

10 START-UP IN 10 YEARS

200 RESEARCH CONTRACTS PER YEAR

800 SCIENTIFIC ARTICLES PER YEAR

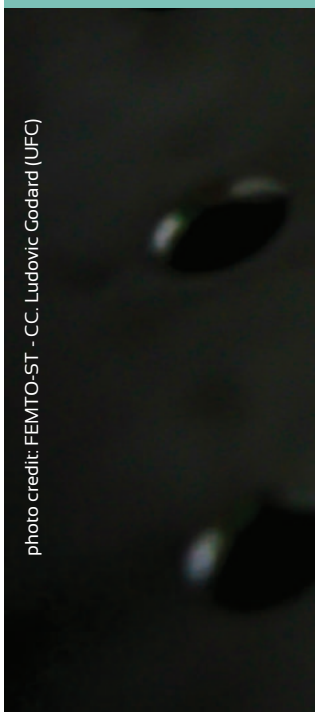

photo credit: FEMTO-ST - CC. Ludovic Godard (UFC)

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