About Leti

Collaborations

Highlights

01 New Advanced Materials: The Fuel of Innovation

02 The Virtues of Photons for the Connected Society

03 Novel Technologies to Improve Human Health

04 Innovative Devices and Architectures for Power Efficiency

05 Interacting Efficiently and Reliably with Complex Systems in the Digital World

06 Strategic Programs
This 2018 edition of Leti’s Scientific Report illustrates beautifully our commitment to innovation in areas such as Quantum Technologies, Artificial Intelligence (AI), Cyber Physical systems (CPS), the Internet of Everything (IoE), Energy Efficiency, Environmental Sustainability and Health Monitoring.

Electronics and nanotechnologies, coupled with AI, are at the heart of the societal challenges of the next few decades. The confluence of fields like resource optimization, health in aging societies, and sustainable environment, transportation, production and trade, is a fascinating evolution which is giving rise to a set of common technological requirements. This is well illustrated by the emergence of the "exposome" model where AI based environmental and health analyses converge.

Generic developments in the application fields of autonomous, low-power interfaces and related sensors will benefit from ultimate integration capabilities and bioinspired approaches. Such fields will also require secure and sustainable solutions, which will present new challenges especially at the edge of the cloud and at the connected objects level. Leti is innovating with disruptive information processing and service paradigms for implementation in dedicated systems and environments, following its R&D strategy along five research axes that span a wide range of emerging topics, from the nano- to the macro-world.

I wish to take the opportunity of this 2018 Scientific Report to thank our scientists, students, and all of our academic and industrial partners for their significant contributions to these achievements.

Finally, I would like to acknowledge my predecessor, Dr. Barbara De Salvo, for her commitment to this report and for her continuous efforts to introduce novel subjects and ideas, encouraging researchers to explore new and challenging scientific fields.

My best regards,
Thomas
Committed to innovation, Leti creates differentiating solutions for its industrial partners.

Leti is a research institute of CEA Tech and a recognized global leader in miniaturization technologies. Leti’s teams are focused on developing solutions that will enable future information and communication technologies, health and wellness approaches, clean energy harvesting and recovery, sustainable transport, space exploration, and cybersecurity.

For over 50 years, the institute has built long-term relationships with its industrial partners, tailoring innovative and differentiating solutions to their needs. Its entrepreneurship programs have sparked the creation of 65 start-ups. Leti and its industrial partners work together through bilateral projects, joint laboratories, and collaborative research programs.

Leti maintains an excellent scientific level by working with the best research teams worldwide, establishing partnerships with major research technology organizations and academic institutions. Leti is also a member of the Carnot Institutes network*.

In 2018, Leti extended its 300mm silicon-based wafer line to open new R&D avenues for its industrial partners. This extension will allow new innovative technological modules to be inserted in, or made compatible with, pioneering industrial process flows that enable edge AI, high-performance computing, in memory computing, photonics, power electronics and other high-end applications. Leti’s industrial partners are now able to develop or test their disruptive technologies and their designs on state-of-the-art equipment, while benefiting from the institute’s R&D expertise.

* Carnot Institutes network: French network of 38 institutes creating innovation with and for industry.
**Awards**

**L’Oréal-UNESCO Women In Science French National Fellowship for development of microfluidic device for early-stage cancer diagnostics**

Eloïse Pariset received the prestigious 2017 L’Oréal-UNESCO Women in Science French National Fellowship for her PhD project “Development of a microfluidic device using Deterministic Lateral Displacement (DLD) for biological sample preparation, towards the extraction of extracellular vesicles.”

This innovative project uses microfluidic technologies to perform portable, standardized, and cost- and time-effective sample preparation from a limited sample volume. In particular, a technique called Deterministic Lateral Displacement (DLD) is used to perform improved filtration of blood samples and cell-culture media. The DLD devices have been optimized to increase their sorting efficiency, which has been demonstrated with biological samples. Coupled with a characterization tool, they are very promising as a first step of EV extraction for early-stage cancer diagnostics.

**JSID’s Best Paper of 2017 for excellence in GaN-based emissive microdisplays**

The Journal of the Society for Information Display conferred its Best Paper of 2017 Award to François Templier for his review paper entitled “GaN-based emissive microdisplays: a very promising technology for compact, ultra-high brightness display systems.”

The work demonstrates different approaches to the fabrication of high-brightness GaN-based emissive microdisplays, with the possibility of applications in augmented reality systems or head-up displays.

**IP Track Best Presentation Award at DAC for demonstration of a low-power IoT platform**

Tibor Stanko received Best Paper Award from the Shape Modeling International Symposium (SMI 2017), held in Berkeley, USA, for his paper entitled “Shape from sensors: Curve networks on surfaces from 3D orientations.” The paper, also published in Computers & Graphics vol.66, was co-authored by N.Saguin-Sprynski of CEA, and S.Hahmann and G.-P.Bonneau of INRA.

The paper describes the development of a complete framework for 3D shape reconstruction; device, acquisition process, and algorithms. Morphisher, a device equipped with inertial sensors rolling on the surface, is used to capture the shape of a surface by curves acquisition.

**Best Paper from SMI 2017 for using sensors to capture shape**

**Best Student Paper Award at the 10th IEEE International Memory Workshop for work on OTS selector devices**

Anthonin Verdy was granted the Best Student Paper Award at the 10th IEEE International Memory Workshop, held in May, 2018 in Kyoto, Japan, for his paper entitled “High temperature stability and performance analysis of N-doped Ge-Se-Sb based OTS selector devices.”

Targeting Crossbar Memory arrays, this work shows the optimization of a Back-End-of-Line (BEOL) selector device based on Chronic Threshold Switching materials (OTS) - making it compatible with temperatures typical of the BEOL integration. After annealing at high temperature, the leakage current of the selector of the Leti team is among the lowest reported so far in the literature, even after cycling.

**IMSE Best Paper Award for innovative thermal imagers**

Laurent Alauxque received the Best Paper Award at the 2017 Image Sensors and Imaging Systems (IMSE) Conference/IS&T International Symposium on Electronic Imaging in Burlingame, USA for his work involving an innovative thermal image sensor—improving processing, privacy and power.

This work is presented in the paper entitled “A 128x128, 3.2um pitch, 8.5umW, 190mK NEDT, TECless Uncooled IR bolometer image sensor with column-wise processing,” which was co-authored by S.Martin, W.Rabaud, É.Beigbeder, and A.Dupret of CEA.

**HiTEN 2017 Best Student Paper Award for work on time domain sensor interface**

The International Conference on HighTemperature Electronics Network (HiTEN 2017) presented Emma Chalchoub with the Best Student Paper Award for her paper entitled “High Temperature, Time Domain Sensor Interface based on Phase Shifters,” which was co-authored by scientists from CEA-Leti, University of Sfax, and LIRMM.

The paper proposes a new sensor readout architecture integrated on a SOI technology dedicated to high temperature applications. The circuit is based on injection locked oscillators which convert the sensor output into a time shift rather than a voltage—getting rid of the usual high drift of silicon components parameters at such high temperatures resulting in a robust solution.
Best Paper Award at ICC 2017 for using waveform to resolve 5G challenges

David Demmer received the Best Paper award from the IEEE International Conference on Communications (ICC), held in Paris in May 2017. The work features a solution to 5G challenges: a flexible waveform which provides a strong spectrum confinement and a backward compatibility to currently deployed LTE systems.


Helmholtz International Fellow Award in recognition of collaboration with FZJ

Jean-Michel Hartmann was honored with the Helmholtz International Fellow Award in July 2017 in recognition of more than 10 years of collaboration between Dr. Hartmann and Forschungszentrum Jülich, as part of European projects and the CEA-FZJ framework agreement. This rich and successful collaboration has resulted in about seventy joint publications in the fields of nanoelectronics and photonics.

This scientific prize aims to distinguish the scientific excellence of researchers based outside Germany. It will strengthen the interactions between the two institutes, through course stays and joint participation in scientific conferences.

Best Student Paper Award at ICICDT 2017 for design of electrostatically-actuated micro/nanoelectromechanical relays

Giulia Usai received the Best Student Paper award at the International Conference on IC Design and Technology (ICICDT 2017) for her study designing electrostatically-actuated micro/nanoelectromechanical relays with a broad operating margin around the supply voltage VDD.

The paper, entitled “Design considerations for optimization of pull-in stability margin in electrostatic N/MEM relays”, was co-authored by L.Hutin, J.L.Muñoz-Gamarra, T.Ernst, and M.Vinet of CEA-Leti, and P.X.-L.Feng of Case Western Reserve University.

S3S Best Paper Award for demonstration of CMOS FD-SOI opportunities

Baudouin Martineau received the Best Paper Award at the IEEE S3S-3D-Subthreshold Microelectronics Unified Conference (S3S), held in San Francisco, USA in October 2017 for his paper entitled «Opportunity of CMOS FD-SOI for RF power amplifiers».

Co-authored by E.Mercier and P.Vincent of CEA-Leti, the paper describes how the fabricated circuit proves that FD-SOI technologies are not only suitable for low power but also for high power RF circuit if the proper design technique is adopted. Furthermore, the paper demonstrates that cost effective integration, in a system-on-chip perspective, is possible.

Electron d’Or for development of the FDSOI technology at 28nm

Electronique Magazine awarded the Electron d’Or to CEA-Leti, STMicroelectronics, and Soitec for their development of FDSOI technology at 28nm. Olivier Faynot was present to receive the award in Paris in June, 2017.

Best Student Paper at ISTFA 2017 for optimizing synchrotron-based x-ray tomography

Alexandra Fraczkiewicz was awarded Best Student Paper at the 43rd International Symposium on Testing and Failure Analysis (ISTFA 2017), held in Pasadena, USA for her work optimizing the sample preparation and the data post-processing of a synchrotron-based x-ray tomography experiment, in order to increase the sample throughput for industrial applications.

The paper, entitled “Making synchrotron tomography a routine tool for 3D integration failure analysis through a limited number of projections, an adapted sample preparation scheme, and a fully-automated post-processing”, was co-authored by scientists from CEA-Leti, University of Grenoble Alpes, ESRF, and STMicroelectronics.
Leti’s Research Directors and International Experts

Lea Di Giacca
Research Director
Bonding techniques, hetero-integration and power devices

Jean-Marc Barten
International Expert
Data, image and signal processing for biomedical devices

Laurent Dussopt
Research Director
Millimeter-wave wireless communication systems, millimeter-wave circuits, antennas & technologies

Jean-Michel Hartmann
Research Director
Epitaxy, hetero-structures for microelectronics and optoelectronics

Suzanne Lesecq
Research Director
Control theory applied to system-on-chip and power electronics, data fusion

Sylvie Mayrargue
International Expert
Wireless communications, digital communications, signal processing, propagation

Christine Raynaud
International Expert
RF technologies and components

Francois Templier
Research Director
Display technologies and systems

Laurent Herault
International Expert
Communication systems, radio-frequency networks and architectures

Thomas Ernst
Research Director
Logic devices and sensors

Olivier Faynot
International Expert
Process integration and devices physics of CMOS technologies

Dominique Morche
Research Director
Circuits and systems design for telecommunication applications

Guy Faussiat
International Expert
Optoelectronics devices, characterisation and physics

Jean-Francois Boulais
International Expert
Optical characterization of micro- and nanodevices

Patrice Gergaud
International Expert
X-ray characterization in micro and nanotechnologies

Pierre Grangaud
Research Director
Data processing for biomedical devices

Olivier Gravrand
Research Director
IR detection and imaging

Alexei Tchelnokov
Research Director
Optoelectronic devices, photonics

Gilles Reimbold
International Expert
Electrical characterization of nanoelectronic devices, physical modeling and reliability

Vincent Jousseau
Research Director
Materials for microelectronics and micro- and nanotechnologies

Suzanne Lesecq
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Sylvie Mayrargue
International Expert
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Laurent Pain
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Lithography - optical, electron beam, imprint

Christine Raynaud
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Alexei Tchelnokov
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Pascal Mailley
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Olivier Faynot
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Process integration and devices physics of CMOS technologies

Dominique Morche
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Yves Faussiat
International Expert
Microfluidics, lab-on-a-chip

Olivier Faynot
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Process integration and devices physics of CMOS technologies

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International Expert
RF technologies and components

Alexei Tchelnokov
Research Director
Optoelectronic devices, photonics

Gilles Reimbold
International Expert
Electrical characterization of nanoelectronic devices, physical modeling and reliability
A new way of depositing chemical sensitive layers on NEMS devices enables better detection of toxic compounds.

A novel approach may take lithography below 10nm.

A new mastery of innovative ion sources enables depth profiling of thin organic films.

Highly customized microbatteries to power emerging applications.

A new understanding of hydrogen tapping mechanisms – insights into improving fabrication of SOI wafers.

New findings on topological insulators impact spintronics and quantum computing.

Shallow germanium surface doping using a molecular layer of antimony.

Towards industrial applications.

With the exploration of novel materials and how best to implement them, we will go beyond the limits of present devices. Will HgTe topological insulators lead to technological advances in the areas of quantum computation and spintronics? Does amorphous lithium titanium oxysulphide, a new thin film electrode material, optimize the efficiency of microbatteries? Does this new variation of monolayer doping allow antimony doping of germanium to boost component performances without leaving behind surface defects? Can direct self-assembly be used for mass production of sub 10nm integrated circuits? These are some questions addressed in the following highlights.
A new way of depositing chemical sensitive layers on NEMS devices enables better detection of toxic compounds

An original CMOS-compatible technique for depositing thin material on wafers enables the development of NEMS based gas sensors.

**BREAKTHROUGH**

An original CVD technique for depositing chemical sensitive layer on silicon, resulting in a very high partition coefficient.

**WHY IT’S RELEVANT**

These organosilicate thin films constitute a promising solution for the development of NEMS based gas sensors.

**MOVING FORWARD**

Development of new chemical layers to detect other toxic industrial chemicals; development of porous organosilicates to detect small molecules in liquids.

Valuable organic compounds are toxic to humans, especially the so-called BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. A promising tool for detecting BTEX compounds is gravimetric sensors based on nano-electromechanical systems (NEMS). One of the key elements of gravimetric sensors is a chemical sensitive layer that collects and concentrates the target molecules.

The challenge is that integrating a chemical sensitive layer onto nanometric devices fabricated on silicon wafers leads to specific material requirements. Solvents can’t be used, because they degrade silicon nanocantilevers; the film has to be thinner than a few hundred nanometers, so it doesn’t fill the gap between the nanocantilever and the electrodes; and the deposition technique must result in a high degree of uniformity over a large surface. Researchers have developed an fabrication technique that meets these requirements and that results in an optimized film exhibiting both high affinity and a rapid temporal response.

What were you able to demonstrate by investigating organosilicate films deposited through variations of chemical vapor deposition (CVD)?

We showed that an organosilicate (SiOCH) layer deposited by filament-assisted CVD using methytriethoxysilane presents very high affinity toward hydrocarbon gas. We obtained high partition coefficients toward toluene (higher than 20,000) and pentane (higher than 1900) on quartz crystal microbalance sensors after annealing at 40°C. We demonstrated that the hydrophobic nature of this material composed of Si-O-Si backbone with methyl groups bonded to the silicon, combined with the presence of isolated ethoxy groups and microporosity, results in a very high sensitivity in comparison with other SOICH. Furthermore, we demonstrated the functionalization of NEMS-based gas sensors.

What new research should be carried out?

We have two areas of future research. The first is to develop other chemical sensitive layers deposited by CVD, such as polymers or metal organic frameworks, and adapted to others gases, such as toxic industrial chemicals (TIC). The second is to develop porous organosilicate thin films to detect small molecules in liquid—for example, polyharmocarbons in water or metabolites in biological fluids.

**COLLABORATIONS**

TEL Technology Center, America, LLC (USA)

**FOR MORE DETAILS**

A low-cost, high resolution and high density patterning technique based on a spin-coating step followed by an etch-back step.

**WHY IT’S RELEVANT**

This technique can be used for mass production of sub 10nm integrated circuits.

**MOVING FORWARD**

Use of new materials, including high-chi materials.

**COLLABORATIONS**

Arkema (France), CEA-Leti (France), Screen (Japan), LPO (France), University of Chicago (USA), National Institute of Standards and Technology (USA)

A novel approach may take lithography below 10nm

The use of conventional lithography to etch patterns on semiconductors has reached its limits at about the 10nm resolution. Consequently, many researchers have turned their attention to a promising class of patterning solutions for sub-10nm nodes—a class of techniques known as directed self-assembly (DSA) of block copolymers (BCP). These techniques are a mix of top down and bottom up approaches, where conventional lithography is used to generate the template that is then used to guide the block copolymer pattern. One of the dominant approaches for DSA is graphoepitaxy, which is used extensively for contact-hole patterning. But a challenge with this approach has been that variation of BCP film thickness inside the guiding template leads to density-related defects in the resulting patterns. This issue prevents the use of DSA in high-volume manufacturing, as different densities can easily exist in a template generated by the classical approach.

A team of researchers developed a new DSA process flow, compatible with 193 immersion lithography, which overcomes this challenge when applied to contact-hole patterning. The process is compatible with line and space patterns and allows for DSA planarization.

What have you done to reduce variations in BCP film thickness?

We developed a process flow called “DSA planarization”, where the patterned surface is planarized with the BCP film by means of appropriate BCP spin-coating and etch-back steps. First, the BCP film is spin-coated onto the wafer with high-film thickness in order to overfill the cavities of all guiding patterns with different opening densities to get a surface as flat as possible. Afterwards, the BCP is self-assembled by thermal annealing, and the extra thickness etched back.

Thanks to DSA planarization, we were able to control the BCP thickness on various pre-pattern densities on the same processed wafer, which could prove very beneficial when applied to the industrial production of semiconductors.

What are the next steps in taking lithography below 10nm?

The first part of our work involved the use of DSA. The second part of our work involved the use of first generation materials, addressing the more relaxed resolution and densities for contact-hole application. The next part of our work is to adapt this new process to generate FINFET nanowires using graphoepitaxy. The first electrical tests on these devices are underway.

We are also ready to work on high-chi materials, which are really high resolution. The hyper density of high-chi materials means changes to the material chemistry; it requires all the processes to be adapted. A new chemo-epitaxy approach is now under implementation.

**FOR MORE DETAILS**

An embedded neutral layer for advanced surface affinity control in grapho-epitaxy directed self-assembly

Edward W. Graebner,1 Francesco Baccarini1, A. Fouquet,2 C. L’Aubé, J. Hazart,2 A. Delechat,1, X. Chevalier,1, C. Fayroux1, L. Pain,1, and R. Tiron1

CEA-Leti,1 Arkema2 Macromolecular Materials and Engineering, vol.302(11), Sept. 2017

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A new mastery of innovative ion sources enables depth profiling of thin organic films

New techniques for depth profiling make it possible to characterize the thin organic films essential to many application areas, including resists used for lithography, organic light emitting diodes (OLEDs), micro-electromechanical systems (MEMS) gas sensors, and flexible electronics.

**To optimize the thin organic films used in so many different applications, designers need to be able to characterize the films under the conditions they will be used. Time-of-flight secondary ion mass spectrometry (TOF-SIMS) has been shown to be a particularly pertinent way of studying the molecular composition of thin organic films. However, until now, because monoatomic ion beams used for sputter depth profiling have tended to destroy the molecular information of interest, the usefulness of TOF-SIMS has been limited to the surface. This challenge has been overcome.**

A team of scientists developed a set of advanced analysis protocols using innovative ion beam sources that can be used to sputter away organic material without damaging the sample. What did you do to enable better depth profiling of thin organic and hybrid layers?

First we benchmarked different ion beam sources using block co-polymer PS/PMMA samples that consist of auto-organized nanostructures of lamella, cylinders, or spheres, depending on the composition and deposition conditions. These benchmarks provided an excellent way to compare the different ion sources available and enabled us to show that large argon clusters are the most versatile—but that low energy cesium and buckminsterfullerene ions (with nitric oxide gas flooding and sample cooling) can also be pertinent for some applications, especially for profiling a hybrid inorganic-organic stack.

Second, we used the protocols developed with large argon cluster and low energy cesium sputtering to address some of the major challenges in the analysis of thin film organic multilayers. For example, we characterized the organization of block copolymer films as a function of annealing temperature by using TOF-SIMS depth profiling with large argon clusters.

Similarly, we studied the effects of aging and environmental barrier efficiency in OLED devices by using the same technique. We showed how the molecular information obtained by TOF-SIMS can be used to identify spectral features that indicate a hydrolysis reaction of ARQ3. Then by following water ions in the barrier, it's possible to determine the water vapor transmission rate as a function of barrier design.

**What new research areas might be explored using your depth profiling techniques?**

The future challenges that will be addressed rely on using correlative approaches that combine TOF-SIMS with other techniques such as XPS, techniques such as XPS, [x-ray photoelectron spectroscopy] and AFM [atomic force microscopy] to produce a unique data set that is more quantitative not only in terms of composition, but also in terms of morphology.

One major challenge in OLED technology is looking at the inorganic-organic interface between the top electrode and the organic stack. We are currently working on developing combined TOF-SIMS and XPS depth profiling using argon cluster sputtering to better understand the effects of electrical ageing in OLEDs. We are also investigating the differences in erosion rates that can occur when performing a 3D TOF-SIMS depth profile as part of an overall study into how to correct the 3D hyperspectral data set using AFM images acquired at different points in the depth profile.

Although this is a generic development that can be applied to almost all types of samples, the differences in erosion rates are particularly pronounced, and thus problematic in organic or hybrid samples. These developments have also allowed us to research ways of providing quantitative analysis (without staining or labeling biological samples) by combining TOF-SIMS, XPS, and AFM analysis on the same sample.

Finally the use of advanced spectrometers is being evaluated as a tool to more accurately identify molecules in the TOF-SIMS mass spectrum.
Highly customized microbatteries to power emerging applications

Interview
FREDÉRIC LE CRAS
Leti scientist

The development of new thin film electrode materials opens up new possibilities for application-specific optimization of microbatteries.

BREAKTHROUGH
Customized electrode material solutions addressing specific feature requirements for all-solid-state thin film batteries (microbatteries).

WHY IT’S RELEVANT
The ability to customize a micro power source provides a way of optimizing devices according to the specific needs of the application.

MOVING FORWARD
Ongoing materials developments (e.g. electrodes, solid electrolyte, and buffer layers) for new needs, such as high temperature operation or implantable bioresorbable devices.

Based on self-powered nomadic, wearable, or implantable miniaturized electronics devices, a new breed of applications is placing new demands on battery technology. Batteries must be embedded in integrated circuits—and they must be highly tailored to a given application. Aspects of a battery that might require application-specific customization include thickness, footprint, flexibility, safety, capacity, and voltage.

All-solid-state thin film batteries, also known as microbatteries, are becoming particularly attractive power sources for this new breed of applications. Along the way we designed and synthesized new thin film electrode materials that make such optimizations possible. For example, we designed microbatteries that use two metal oxide systems that undergo a two-phase reaction during lithium intercalation to deliver a stabilized voltage at three volts during operation. Another example is that we developed amorphous lithium titanium oxysulphide thin films. We did this to obtain a low-voltage, high-capacity lithiated positive electrode material for solder-reflowable lithium-ion microbatteries.

What new research areas are now possible thanks to the in-depth knowledge you’ve acquired on all-solid-state thin film battery materials?
We are currently carrying out research in three main areas. One is with the goal of developing biocompatible and bioresorbable microbatteries, mainly based on compounds containing iron or magnesium, for transient implantable microdevices. Another area of research is to optimize all-solid-state microbatteries for operation at high temperatures (approximately 200°C), by selection of materials not just for their electrochemical behavior at room temperature, but also for their structural and thermal stability, and their thermo-mechanical properties and reactivity at the solid-to-solid interfaces. Then our third area of research is aimed at developing inorganic solid lithium ionic conductors (glasses) with enhanced conductivity, in order to build microbatteries that deliver higher current pulses.

What have you done to advance the understanding of microbatteries?
We carried out a series of studies to better understand what it takes to change various features of microbatteries. Along the way we designed and synthesized new thin film electrode materials that make such optimizations possible. For example, we designed microbatteries with two metal oxide systems that undergo a two-phase reaction during lithium intercalation to deliver a stabilized voltage at three volts during operation. Another example is that we developed amorphous lithium titanium oxysulphide thin films. We did this to obtain a low-voltage, high-capacity lithiated positive electrode material for solder-reflowable lithium-ion microbatteries.

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COLLABORATIONS
University of Bordeaux (France)
STMicroelectronics (France)
University of Pau (France)

FOR MORE DETAILS
Dual cation- and anion-based redox process in lithium titanium oxysulfide thin film cathodes for all-solid-state lithium-ion batteries
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Iron molybdate thin films prepared by sputtering and their electrochemical behavior in Li batteries
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A new understanding of hydrogen trapping mechanisms – insights into improving fabrication of SOI wafers

**BREAKTHROUGH**
A better understanding of hydrogen trapping mechanism in Si/Si/Si structures.

**WHY IT’S RELEVANT**
This new understanding can further improve the fabrication process of next generation of SOI wafers via Smart Cut™ technology.

**MOVING FORWARD**
Extending the approach to fabrication of other advanced substrates, such as Strained Silicon On Insulator (sSOI), SiGe On Insulator (SGOI) or Ge On Insulator (GoI).

Many electronic and sensor devices are fabricated using Silicon-On-Insulator (SOI) wafers. Most of these wafers are manufactured using Smart Cut™ technology, invented by Leti and industrialized by Soitec—a Leti partner. In this process, a silicon wafer is implanted by hydrogen ions, bonded to another wafer, and then annealed. The SOI wafer is obtained by splitting the silicon at the depth where the hydrogen was implanted and where it precipitates during annealing.

In principle, this depth can be adjusted through the implantation energy. But the depth-distribution of hydrogen after implantation inevitably results in variations of thickness and roughness of the transferred layer. Advanced devices require 300 nm SOI wafers. The silicon top layer of these wafers should only be a few nanometers thick (typically 8 to 10 nm). The wafers should have only very small variations in thickness and roughness—variations of no more than 0.5 nm over the whole wafer.

To meet these requirements, carefully optimized finishing steps have to be added to the fabrication process to overcome the variations. These finishing steps take time and money, reducing yield and increasing cost.

An interesting approach for overcoming the variation is to introduce hydrogen-trapping centers into the donor substrate to further improve the localization of hydrogen related cracks. But until now, not enough was known about the ingredients and mechanisms behind this process.

This has now changed. A team of researchers recently conducted experiments to further the understanding of hydrogen trapping mechanisms, which could be used to further improve the fabrication process of the next generation of SOI wafers.

What did you find out through your experiments on hydrogen trapping?
We experimentally studied the effect of the presence of a boron-doped 5 nm-thick silicon layer buried into pure silicon onto the redistribution and precipitation of hydrogen after implantation and during thermal annealing. We showed that the silicon-boron layer already traps hydrogen during implantation and it forms platelets parallel to the wafer surface. During annealing, the hydrogen atoms implanted in the silicon regions are slowly transferred toward the silicon-boron layer, where they are stored on large platelets, which grow still further during annealing.

This mechanism minimizes hydrogen precipitation in the pure silicon regions, and then force the splitting to occur in the ultrathin boron doped layer. We have already demonstrated a reduction in roughness, having used this approach for post splitting SOI wafers for a decade. We think we can further improve the localization of hydrogen related cracks by optimizing the implantation and anneal conditions.

What new possibilities result from your work with SOI?
Our approach can be extended to the fabrication of other advanced substrates, such as strained silicon on insulator (sSOI), SiGe on insulator (SGOI) or Ge on insulator (GeO).

What new evidence has the potential to revolutionize spintronics?
Not only do they possess a very strong spin-orbit interaction, but electrons in the form of Dirac fermions also carry a unique property of having their spins locked to their momentum, allowing for naturally polarized spin currents. Together with the fact that topological insulators experience a large spin-to-charge conversion on surfaces, these properties lead to the expectation that topological spintronic devices could considerably drive down electrical consumption and drive up spin-to-charge conversion efficiency.

Because topological insulators promote the appearance of Majorana’s particles at the point where they interface with superconductors, they might also provide a good foundation for computing superconducting platforms.

Applying their know-how in the epitaxial growth of crystalline Hg- semiconductor, team of scientists conducted studies on the transition between a 2D and a 3D topological insulator when the thickness of the mercury telluride (HgTe) layer is varied.

What was unique about your findings and where did those findings lead you?
We were the only group to detail the particular regime in which the Dirac electron wave function at the two interfaces begins to overlap and couple, resulting in a small hybridization gap. To particular, we obtained the extremely clear Quantum Hall signatures of pure Dirac fermion surface states without any bulk contribution to the electronic transport.

In order to exploit the unique spin polarization properties predicted for strong topological insulators, we have now used this new topological material to perform spin injection from a resonant ferromagnetic material. We demonstrated the first spin-pumping experiment with HgTe topological structures, and obtained record spin-to-charge conversion efficiency at room temperature. This opens up possibilities for new kinds of spintronic devices that exploit topological surface spin conversion.

What new research questions arise from your findings in the areas of spintronics and quantum nanoelectronics?
There are two main directions we want to pursue. The first is to make a magnetic insulator-to-superconductor interface, with one being to experimentally demonstrate the existence of Majorana fermions in this system. Fermions are particles with no charge and no spin, and therefore are virtually insensitive to perturbation. They are the best candidates today for storing quantum information and serving as the building block for topological quantum bits.

The second direction, with more immediate practical applications, is topological spintronics. We are investigating the spin-to-charge and reversed charge-to-spin conversion properties in hybrid topological insulator / ferromagnetic structures.

**COLLABORATIONS**
(CNRS, France) CEA-LETI, CNRS-ISTEC (France); CEA-LETI, CNRS, Institut Néel, Grenoble; CNRS, Inst NEEL, Univ Grenoble Alpes, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; CEA-INES, Univ Lyon, ENS Lyon, Univ Claude Bernard.

**FOR MORE DETAILS**
Physical Review Letters, vol.120(16), April 2018

**FOR MORE DETAILS**
Highly efficient spin-to-charge conversion at room temperature in strained HgTe thin films via quantum hall transport spectroscopy

Christopher Thomas1, Olaf Paulussen1, B. Haas1, P-H Jouneau1, C.Bauerle3, 1L.Paulussen4, E. Dignac5, P. Carpentier5, F.Ballet6, and T.Meunier1

1CNRS, Inst NEEL, Univ Grenoble Alpes, Inst NEEL; 2CEA-Inac, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; 3CEA-Inac, Inst NEEL, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; 4CEA-Inac, Inst NEEL, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; 5CEA-Inac, Inst NEEL, Univ Lyon, ENS Lyon, Univ Claude Bernard, CNRS, Inst NEEL; 6CEA-Inac, Inst NEEL, Univ Lyon, ENS Lyon, Univ Claude Bernard.

**FOR MORE DETAILS**
Topological insulators promote the appearance of Majorana’s particles at the point where they interface with superconductors, they might also provide a good foundation for quantum computing platforms. We demonstrated the first spin-pumping experiment with HgTe topological structures, and obtained record spin-to-charge conversion efficiency at room temperature. This opens up possibilities for new kinds of spintronic devices that exploit topological surface spin conversion.

**FOR MORE DETAILS**
Topological insulators are expected to revolutionize spintronics. Not only do they possess a very strong spin-orbit interaction, but electrons in the form of Dirac fermions also carry a unique property of having their spins locked to their momentum, allowing for naturally polarized spin currents. Together with the fact that topological insulators experience a large spin-to-charge conversion on surfaces, these properties lead to the expectation that topological spintronic devices could considerably drive down electrical consumption and drive up spin-to-charge conversion efficiency.

Because topological insulators promote the appearance of Majorana’s particles at the point where they interface with superconductors, they might also provide a good foundation for computing superconducting platforms. We demonstrated the first spin-pumping experiment with HgTe topological structures, and obtained record spin-to-charge conversion efficiency at room temperature. This opens up possibilities for new kinds of spintronic devices that exploit topological surface spin conversion.

What new research questions arise from your findings in the areas of spintronics and quantum nanoelectronics?
There are two main directions we want to pursue. The first is to make a magnetic insulator-to-superconductor interface, with one being to experimentally demonstrate the existence of Majorana fermions in this system. Fermions are particles with no charge and no spin, and therefore are virtually insensitive to perturbation. They are the best candidates today for storing quantum information and serving as the building block for topological quantum bits.

The second direction, with more immediate practical applications, is topological spintronics. We are investigating the spin-to-charge and reversed charge-to-spin conversion properties in hybrid topological insulator / ferromagnetic structures.
A new variation of monolayer doping (MLD) allows antimony doping of germanium, without leaving surface defects behind.

**Interview**

**FRANÇOIS MARTIN**

Leti scientist

**Shallow germanium surface doping using a molecular layer of antimony**

**BREAKTHROUGH**

Extreme surface doping of germanium by a heavy atom (antimony) without leaving defects.

**WHY IT’S RELEVANT**

An alternative to very low implantation energy, this work provides a way to avoid defects while maximizing dopant concentration at the semiconductor surface.

**MOVING FORWARD**

Adaptation of these techniques to any deposition of monolayers containing a dopant (ALD and others) and emerging anneals, such as laser.

As demand for high-performance devices grows, so does the interest in all the things that make up high-performance devices, including emerging materials, such as metal-oxide-semiconductor field-effect transistors or photodiodes. Consequently, researchers have turned their attention back to germanium (Ge), with its higher electron and hole mobilities, as compared to silicon, and because of its photovoltaic properties. A major challenge in using Ge, however, has been in achieving defect-free doping. When the commonly used ion-implantation technique is used to implant a heavy metal dopant into a Ge substrate, the process results in structural defects that cannot be removed by conventional annealing.

An alternative method of doping, referred to as either monolayer doping or molecular monolayer doping (both terms conveniently take the same abbreviation: MLD), works by diffusing the dopant from grafted, self-assembled molecules, into the substitute lattice sites below the surface of the semiconductor material. MLD is much milder than ion implantation, and has been demonstrated to yield abrupt junctions (0.6 nm/dec) with reduced depths not exceeding 5 nm. But for heavy atom doping of Ge in particular, this doping technique is still in its infancy. It comes with limitations originating from the lower thermal budget available for dopant activation, as compared to a silicon substrate, and from issues related to the n-type dopant evaporation.

Researchers have overcome this challenge to come up with a new variation of MLD that allows extreme surface doping of germanium by a heavy atom—in this case, antimony—without causing defects.

Researchers have developed a “self-capping” molecule, made of a nanosilica-like cage, was developed to avoid dopant evaporation. But this is not efficient enough to keep the antimony from evaporating while the dopant is driven into germanium. To overcome this problem we developed a passivation—a low temperature plasma-enhanced atomic layer deposition (PEALD) oxide at 50°C, compatible with 300mm manufacturing—to replace non-conformal SiO2 evaporation. This latter technique is commonly used in the literature.

What are the key features of your technique that make it an attractive alternative ion-implantation?

We applied the molecular layer-doping (MLD) concept to dope germanium with antimony and we investigated ways of incorporating antimony dopants into the germanium and electrically activating the antimony. Our monolayer doping strategy was based on controlled grafting of antimony precursors followed by diffusion of antimony into the wafer through annealing. A “self-capping” molecule, made of a nanosilica-like cage, was developed to avoid dopant evaporation. But this is not efficient enough to keep the antimony from evaporating while the dopant is driven into germanium. To overcome this problem we developed a passivation—a low temperature plasma-enhanced atomic layer deposition (PEALD) oxide at 50°C, compatible with 300mm manufacturing—to replace non-conformal SiO2 evaporation. This latter technique is commonly used in the literature.

We highlight the key role of citric acid in passivating the surface before its reaction with the antimony precursors and the benefit of the protective SiO2 layer over that enables an efficient, shallow incorporation of activated antimony, as shown by the diode characteristic measured after dopant drive-in.

This method should be appropriate when any heavy atom is used as dopant on emerging devices.

Where else can your variation on MLD be applied?

The availability of laser annealing in Leti can open new possibilities to perform high concentration of surface dopant for emerging nanodevices. The principle of molecular grafting could be adapted towards atomic layer deposition (ALD) of thin nanometric dopant containing oxide, which is already used to dope the edge of advanced FINFETs. Our work could extend this capability to dope emerging devices requiring high surface doping concentrations when germanium is involved—for example, contacts and diodes for nanodevices or optoelectronic devices. Our work provides an alternative to low energy implantation, preventing residual defects and tailoring the maximum concentration of dopants at the outer interface of semiconductor.

**COLLABORATIONS**

University of Lille (France)

CPE Lyon (France)

ETH Zurich (Switzerland)

For more details, see the interviews with researchers in the literature.
Towards industrial applications

LETI AND SOITEC LAUNCH A NEW SUBSTRATE INNOVATION CENTER TO DEVELOP ENGINEERED SUBSTRATE SOLUTIONS

Industry-inclusive hub promotes early collaboration and learning from substrate to system level

SAN FRANCISCO and GRENOBLE, France – July 10, 2018 – Leti, a research institute of CEA Tech, and Soitec, a world leader in designing and manufacturing innovative semiconductor materials, today announced a new collaboration and five-year partnership agreement to drive the R&D of advanced engineered substrates, including SOC and beyond. This agreement brings the traditional Leti-Soitec partnership to a whole new dimension and includes the launch of a world-class prototyping hub associating equipment partners to pioneer with new materials. The Substrate Innovation Center will feature access to shared Leti-Soitec expertise around a focused pilot line. Key benefits for partners include access to early exploratory sampling and prototyping, collaborative analysis, and early learning at the substrate level, eventually leading to streamlined product viability and roadmap planning at the system level.


A NEW GENERATION OF SENSORS

Leti’s work on chemical sensors ensures its unmatched expertise in technologies for integrating spectroscopic solutions for gas (air quality, industrial monitoring via sensor networks, etc.) and water analysis. In recent years, several start-ups have been created to develop this type of technology: APIX, eLichens, MirSense. Our institute also operates a state-of-the-art electrochemical platform.


Apix eLichens mirSense

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MORE DETAILS:
The Virtues of Photons for the Connected Society

From the terahertz band to X-rays, photonic technologies generate, emit, detect, collect, transmit, modulate, and amplify photon beams. Behind this pedantic definition lies an exploding and exciting field, solidly weaved into each moment of our everyday lives: lighting, imaging, displays, data transmission with optical fibres, medical examinations, environmental sensors, industry, road vehicles, aerospace, and more.

This year’s highlights are a very small subset of what we, at Leti, are doing in photonics: improving the speed of future multi-kernel microprocessors with a high-density optical network moving data inside an electronic chip; combining bulk and single-atomic-layer, two-dimensional semiconductors to access new paths toward better optoelectronic devices; a paradigm shift in imaging capturing and projecting devices; ultra-compact, bright and power-efficient micro-displays that illustrate our deep physical understanding of how they operate; and an unexpected way to see better with infrared light.

Thermal management of microrings results in higher density optical network-on-chip

Combining 2D and 3D materials for improved optoelectronic and photodetection devices

Better optical systems — it’s all about the curvature

Micro-LED geometry improves the ABC model, a key tool in designing micro-LEDs

A more reliable way of sensing infrared radiation, even with decreased pitch

Towards industrial applications
Thermal management of microrings results in a higher density optical network-on-chip

A new design for on-chip optical communication uses a feedback loop to overcome wavelength shifts that result from self-heating.

The objective of optical network on a chip is to increase the density of integration, measured in terabits/second/mm². To achieve this goal, designers have to minimize overhead on the circuit area that provides distributed communication on a silicon photonic interposer. Because of their very compact footprint, microring optical resonators have been a primary focus of research.

The biggest challenge is to keep the resonance wavelength of the rings tuned to the laser wavelength as temperatures change. The denser the system, the more it self-heats as chip activity increases—and the more resonance wavelengths shift as a result. A team of scientists recently overcame this challenge.

Now that you’ve found a way to maintain constant wavelength in spite of self-heating, what areas of research will further advance optical network-on-chip?

Our goal is to develop a multicores processor made of several chiplets assembled on a photonics interposer. To this end, we have already designed a photonic topology suited to the tiling of identical chiplets, and a protocol to handle the flow-control, routing, and arbitration of the optical transmissions between chiplets. We are now working on the system-level integration of these circuits.

Another area of research is to investigate applications that would benefit from the resulting computing power—to improve their performance and consider the impact of intensive workloads on the chip temperature distribution. Our goals are to minimize the periods of unavailability during wavelength remapping and to minimize the overall thermal power budget. We plan to use different strategies to limit the risk of local thermal runaways, by scheduling the application threads on the most relevant cores, by varying the frequencies and voltages of each core, and by creating warning levels to schedule the unavailability periods at the time they would impede the application the least.

**COLLABORATIONS**

STMicroelectronics (France)
Institut des Nanotechnologies de Lyon (France)
Hong-Kong University of Science & Technology (China)
Columbia University (USA)
Boston University (USA)

**FOR MORE DETAILS**

A 10Gbps Si-photonic transceiver with 1.5pslock-time digitally supervised analog microring wavelength stabilization for 1.75Tbps die-to-die optical networks

Y. Thonnart, B. Charbonnier, L. Boutafa, B. Karakus, J. M. Hartmann, M. Zid, G. Waltener, S. Brision, C. Baudot

CEA-Leti, STMicroelectronics


CMOS compatible 200nm silicon photonic platform suitable for high bandwidth applications

B. Saelig, B. Charbonnier, S. Brision, B. Karakus, J. M. Hartmann, M. Zid, G. Waltener, S. Brision, C. Baudot

CEA-Leti, CEA-Leti, C2N, Univ. Paris Sud, Univ. Paris Saclay

Proc. of the International Conference on Solid State Devices and Materials (SSDM), Sept. 2017

**BREAKTHROUGH**

Robust microring-based high-density optical chip-to-chip communication on interposer that overcomes the problems of self-heating (1Tbps/mm² density, 1pm accuracy, 1kHz, robustness, 100μs lock time).

**WHY IT’S RELEVANT**

Chip-to-chip optical communication will enable denser and more energy efficient high-performance computers and data servers.

**MOVING FORWARD**

System-level integration in an applicative environment; high-level temperature management to minimize the performance impact in a reduced power budget.
Combining 2D and 3D materials for improved optoelectronic and photodetection devices

Hybrid systems that combine crystalline bulk semiconductors with 2D crystals open up new possibilities for optoelectronic applications—for example, the combination of gallium nitride (GaN) and graphene provides a promising new platform for high-gain UV photodetectors.

**BREAKTHROUGH**
Demonstration that under specific nucleation conditions, graphene withstands the severe atmosphere required to grow GaN crystals.

**WHY IT’S RELEVANT**
This demonstration ushers in a new way of building self-assembled 2D/III-V hybrid optoelectronic devices through a direct epitaxy of Van der Waals type.

**MOVING FORWARD**
Creation of new types of junctions through 2D-3D Integration.

Thanks to its high carrier mobility, high stability, and easy fabrication, graphene is well suited for photodetection. However, the responsivity of purely graphene-based photodetectors is limited by graphene’s weak light absorption. GaN materials, on the other hand, have a wide band gap, which makes them highly efficient absorbers of UV-A, UV-B, and UV-C. For these reasons, the combination of GaN and graphene was recognized as a way of taking full advantage of the electronic properties of graphene during the epitaxial growth process and subsequently using it as an active material.

What new research needs to be carried out to extend these techniques to other combinations of materials? It’s possible to integrate 2D/3D structures to create new types of functional devices. However, the main challenge lies in developing the right processes that take into account the properties of this new class of materials. Most of the literature so far focuses on graphene. But we intend to advance the state of the art by using other 2D materials, such as transition metal dichalcogenides (TMDs), which are potentially a good fit for this heterogeneous integration—possibly as long as they remain stable at high temperature.

**Interview**
BERANGÈRE HYOT AND TIMOTÉE JOURNOT
Leti scientists

**Better optical systems— it’s all about the curvature**

Optimal curvature of components and microdisplays impacts a variety of applications from professional photography to computer vision.

**BREAKTHROUGH**
Techniques for optimizing the curvature of optical components.

**WHY IT’S RELEVANT**
Optimal curvature of components results in more compact optical systems, better image quality, and an extended field of vision.

**MOVING FORWARD**
Collective curvature of optical components; adjustable curvature.

Much of the recent research in improving the packaging of imaging systems (image sensors and microdisplays) has focused on two important areas. The first is reducing the size of system components; the second is improving the quality of images by removing off-axis aberrations, such as Petzval Field Curvature and astigmatism.

Most of the work to overcome these two challenges involves curving the optical components—giving them a spherical, cylindrical, or aspherical form. An added advantage to this approach is that, as is the case of the human retina, the curvature of optical sensors extends the field of vision.

Collaborators: CEAT, Inac-PHILIOS (France); CNRS, Institut Niel (France)

**FOR MORE DETAILS**

Collaborations: University of Aix Marseille, CNRS, LAM (France)

**Interview**
DAVID HENRY
Leti scientist

**FOR MORE DETAILS**


Collaborators: CEA-Leti, University of Aix Marseille, CNRS, LAM, and B.Hyot, and T.Behaghel, S.Gétin, T.Behaghel, S.Caplet, E.Hugot, W.Jahn, and M.Ferrari

CEAT, Lam, Sensors Belgium


Collaborators: CEA-Leti, University of Aix Marseille, CNRS, LAM, and B.Hyot, and T.Behaghel, S.Gétin, T.Behaghel, S.Caplet, E.Hugot, W.Jahn, and M.Ferrari

CEAT, Lam, Sensors Belgium

Micro-LED geometry improves the ABC model, a key tool in designing micro-LEDs

A new understanding of how device geometry determines quantum efficiency in micro-LED will help designers respond to market demands for improved displays on low-power devices.

**BREAKTHROUGH**

An improved understanding of how micro-LED geometry determines a number of characteristics of micro-LEDs.

WHY IT’S RELEVANT

Designers need accurate models to help them design displays to meet the growing demand for low-powered wearables with high-quality displays.

MOVING FORWARD

Optimization of GaN based micro-displays in terms of micro-LED efficiency, brightness uniformity, and defect reduction.

What led you to study micro-LED geometry and what new discoveries have you made?

In the course of our research we observed that quantum efficiency depends on LED geometry, a dependency that isn’t taken into account by the ABC model. We then set out to conduct a comprehensive study to find out precisely how geometry relates to the non-radiative (A), radiative (B), and droop (C) parameters.

Our results demonstrated that parameter A is strongly correlated to LED size—and more precisely increases with the perimeter-to-area ratio of the LED. By contrast, parameters B and C seemed not to vary with geometry.

Moreover, these findings strongly denote that sidewall defects play a major role in LED performance. For this reason, we have suggested a modification of the ABC model to take into account the device geometry. This insight will improve the state of the art by improving the understanding and development of micro-LEDs dedicated to micro-displays.

What new research questions need to be answered to further improve our understanding of micro-LEDs?

Even though a lot of progress has been made in the comprehension of micro-LED devices, including material processing and fabrication, there are still many challenges to tackle in order to optimize the GaN based micro-displays. Potential areas of optimization include, for example, micro-LED efficiency, brightness uniformity, and defect reduction. One of the most challenging paths to explore is producing a complete full color (RGB) micro-display.

COLLABORATIONS

ILL-Lab (France)

FOR MORE DETAILS

Shockley-read-hall and auger non-radiative recombination in GaN based LEDs: a size effect study.


Influence of size-reduction on the performances of GaN-based micro-LEDs for display application


A more reliable way of sensing infrared radiation, even with decreased pitch

A new method for fabricating high frequency resonant sensors with a low temperature process will do more than just improve the state of the art of thermal imaging systems.

**BREAKTHROUGH**

First demonstration of a low temperature fabrication process for high frequency sensors that is fully CMOS compatible.

**WHY IT’S RELEVANT**

A process for fabricating small pitch IR imagers on CMOS yields more imagers per wafer.

MOVING FORWARD

Research into a new type of material, with phase transition, to increase temperature sensitivity; design of a new readout scheme to control the resonant frequencies of a large number of pixels.

Microbolometers are the most prominent technology used to develop infrared focal plane arrays (IFPA) with large pixel counts—essential components of a variety of modern thermal imaging systems. Including night vision, thermography, surveillance, firefighting, and assisted driving.

Microbolometers operate by converting changes in heat of a thin membrane, induced by infrared (IR) absorption, into changes in electrical resistance. The sensitive part of a microbolometer pixel acts as a thermistor; and state-of-the-art implementations exhibit a noise equivalent temperature difference (NETD) close to 50 mK for small-pitch microbolometers.

A key area of research is in finding ways of decreasing pixel pitch without changing temperature sensitivity. Decreasing pixel pitch results in increased pixel count and lower per-unit costs, which in turn leads to more attractive pricing for the consumer market.

A big challenge is that, as you decrease the pixel pitch you raise the vulnerability of the overall system to self-heating. When the sensing material is exposed to excessive radiant power (for example, from the sun), its temperature can increase dramatically, causing a detrimental drift in the thermistor properties.

To address this challenge, researchers have developed a unique pixel architecture where the thermistor is replaced by a high-frequency mechanical nanoresonator designed to be ultra-sensitive to IR radiation.

What is the most important challenge you have faced in your research and what do you think is the next step?

We demonstrated the great potential of high frequency resonant sensors fabricated with a low temperature process dedicated to uncooled infrared imaging. We developed a complete electrical transduction to drive and read the useful signal according to calibrated temperature variations. Using a figure of merit NETD = $x \cdot T / A_p$, we showed that our device gathers the best features compared to other resonant thermal sensors.

The first big impact of this technology is that it provides a new way of producing small pitch IR imagers. Small pitch means fabricating more imagers per wafer, which puts downward pressure on the price per unit.

But our system has applications beyond imagers. For example, it could be used as a calorimeter at the level of a single biological cell. It would measure heat exchanges between cells, or between a cell and a temperature reservoir. These heat exchanges are intrinsic properties of cells that can be used to distinguish healthy tissue from cancerous tissue. What further research will best reap the benefits of your new system for developing high frequency sensors?

We have two sets of challenges. The first is to further improve the temperature sensitivity for small pitches, even though the figure of merit shows that our approach is more efficient than the current microbolometer. To do so, the first order phase transition of a specific material can be used to obtain Young’s modulus that are highly sensitive to temperature, thereby increasing the temperature coefficient of the frequency. We’ve already started this work, and it is ongoing.

The second area of work is that the micro-oscillators have to be read through a phase locked loop. This kind of electronics is very different compared to current electronics dedicated to a resistance variation measurement—that is, the electronics of microbolometers. We also need to develop a new readout scheme that makes it possible to read and control the resonant frequencies of a large number of pixels.

COLLABORATIONS

Kavli Nanoscience Institute at Caltech (USA)

FOR MORE DETAILS

Array of resonant electromechanical nanosystems: a technological breakthrough for uncooled infrared imagers.

L. Laurenti, J.-S. Moulet, J-A. Cucuruzhe, and J. Delpruuy, CEA-Leti, Kavli Nanoscience Institute, California Institute of Technology

Physical Review Applied, vol.10(2), Feb. 2018

12µm-pitch electromechanical resonator for thermal sensing.


Micromachines 2018, vol.9(8), Aug. 2018
**LETI SILICON PHOTONICS DESIGN KIT AVAILABLE FOR SYNOPSYS OPTODESIGNER PIC DESIGN SOLUTION**

GRENOBLE, France – April 05, 2018 – Leti, a research institute of CEA Tech, today announced Leti’s silicon photonics process design kit (PDK) for photonic circuits is available in the Synopsys PhoeniX OptoDesigner suite.

Leti’s integrated silicon photonics platform has been developed for high-speed optical transceivers and highly-integrated optical interposer applications. The process design kit contains the design rules and building blocks for multi-project wafer and custom runs on Leti’s Si310 platform. It also includes a catalogue of components available at Leti, allowing Synopsys PhoeniX OptoDesigner customers to select the ones they need to build their circuits. Once the customers have a completed circuit design, Leti produces a proof of concept on a multi-project wafer run.

**MIRPHAB OFFERING DESIGN, PRODUCTION AND BUSINESS PLANNING FOR COMPANIES DEVELOPING MID-INFRARED DEVICES FOR CHEMICAL SENSING AND SPECTROSCOPIC APPLICATIONS**

GRENOBLE, France – Nov. 12, 2018 – MIRPHAB, a European Commission project to create a pilot line to fabricate mid-infrared (MIR) sensors by 2020, is accepting proposals from companies that want to develop and prototype new MIR devices that operate in gas and liquid media.

Companies Can Submit Proposals for Possible Matching Funds to Help Develop Prototypes

GRENoble, France – Nov. 12, 2018 – MIRPHAB, a European Commission project to create a pilot line to fabricate mid-infrared (MIR) sensors by 2020, is accepting proposals from companies that want to develop and prototype new MIR devices that operate in gas and liquid media.

**MORE DETAILS:**


http://bit.ly/2QNkzCh
Highlights

Novel Technologies to Improve Human Health

Improving the quality of life is a major challenge of the 21st century, encompassing not only human health but also food quality and the environment. Micro and nanotechnologies can provide relevant solutions, from in vitro diagnostics or imaging tools that deliver usable signals and images to medical staff and patients to vectorization and delivery of active medicines or vaccines. Nevertheless, the design of these tools and their actual application in a complex environment—complexities of the analytical media and/or measured signals, multiplicity of biomarkers or data to be analysed, etc.—requires a constant evolution of data processing and fusion in order to generate reliable measurements that can go as far as the implementation of complex action or feedback chains. It is in this context of increasing dichotomy between tools and digital technology that the future of health technologies lies.

An innovative class of hydrogel-based materials offers new possibilities for rate-controlled drug delivery systems

A novel microfluidic device helps detect bacteria in very low concentrations, very rapidly

A new imaging system, based on X-ray diffraction, enables second-level screening of breast cancer in vivo

A new bio-inspired learning algorithm translates brain signals to movement of prosthetic devices

Better estimates of energy expenditure improve artificial pancreas

Time-resolved optical imaging enables non-invasive monitoring of free flaps

A new nanoparticle-based vaccine delivery system improves immune response

Towards industrial applications
An innovative class of hydrogel-based materials offers new possibilities for rate-controlled drug delivery systems

**BRAcKTHROUGH**

Interpenetrated polymer networks for designing biomaterials with reinforced mechanical properties; lipid nanoparticle/hydrogel biomaterials for lipophilic drug loading and controlled release.

**WHY IT’S RELEVANT**

This new biomaterial provides a vehicle for drug delivery with limited side effects and controlled release.

**MOVING FORWARD**

Enhancement of materials, based on targeted use: processing of large batches and integration of material into complete delivery systems.

Because of their biocompatibility and sometimes bioactivity, hydrogels based on biopolymers such as cellulose derivatives, chitosan or hyaluronic acid, are particularly interesting for medical applications, such as drug delivery systems or tissue engineering.

However, one challenge has been that the irregular pore distribution and high water content of most hydrogels often result in rapid and uncontrolled release of small water-soluble molecules. Another challenge has been that, because of the incompatibility between the hydrophobic drug molecules and the hydrophilic polymer network, loading hydrophobic medicines into hydrogels causes rapid burst release.

A team of researchers overcame these challenges by developing a new class of CS sponges, consisting of an interpenetrating polymer network (semi-IPN) of chitosan and PEG to control material properties, such as stability in physiological conditions and mechanical properties—a higher Young’s modulus—and stability at physiological pH. This ability to modulate the porosity and mechanical properties of such interpenetrating materials is of high interest for rate-controlled drug delivery systems.

We had a second breakthrough, which involved using lipid nanoparticles (LNP) that encapsulate big payloads of lipophilic molecules to be entrapped within the hydrogel matrix to achieve localized and sustained release of lipophilic drugs. LNP release from the hydrogel matrix was quantified using dye-loaded LNP as a drug model, and comparing the results with a mathematical diffusion model based on Fick’s second law. We prolonged the initial LNP release rate by increasing the particle diameter from 50 nm to 120 nm, and we adjusted the amount of long-term release by tailoring the particle surface charge or the crosslinking density of the hydrogel. After 30 days, 98% of the 50 nm negatively charged LNP diffused from the material. By contrast, only 17% of positively charged nanoparticles were released from hydrogels with intermediate crosslinking density.

**WHAT NEW RESEARCH FOLLOWS THIS FIRST PROOF-OF-CONCEPT OF HYBRID HYDROGEL-LIPID NANOPARTICLE MATERIALS?**

The first new area of focus is to improve and enhance the properties of the materials based on their targeted use. For example, in cases where the goal is to implant a drug delivery system, we will modulate the material biodegradation kinetics by changing the number of crosslinks of the IPNs. Another example is that we are also presently working on an innovative design to improve the material elasticity for application on the skin.

The second area of research is to develop methods for processing large batches of material and integrating the material into complete drug delivery systems.
Scientists have developed a device and method that enables the detection of fewer than ten targeted bacterial cells in one milliliter of sample, within less than one hour.

**BREAKTHROUGH**
A device and method for preparing samples that enables a detection rate of fewer than ten targets per one milliliter of sample in less than one hour.

**WHY IT’S RELEVANT**
This new approach makes it possible to detect contaminated food within one hour.

**MOVING FORWARD**
Integration of sample preparation and molecular detection on a single handheld device to provide a portable and low-cost solution for use in the field.

To overcome this challenge, Leti scientists have developed a way of detecting contamination in a shorter time than the industry needs. A novel microfluidic device with new optical technology, and a new method to concentrate, purify, and lyse bacteria to output pure DNA for an amplification solution.

What are the next steps to build on the prototypical device and method for detecting contaminants?
In the future we plan to render the device totally portable by including an isothermal DNA amplification and a new detection method on the same platform. This platform will make it possible to rapidly detect bacteria in low concentrations, and even in spore form, in situ, far from the laboratory.

**COLLABORATIONS**
Dr. Marcoule, L2ID, CEA, DRF, Joliot, SPI (France) CNRS, Grenoble INP, LCGP (France) Support from NBCR-E et PCT-2018

**FOR MORE DETAILS**

Screen-printed polyaniline-based electrodes for the real-time monitoring of loop-mediated isothermal amplification reactions.

What new information does your technique provide beyond what is currently available?
Scientists developed a new complementarity based on X-Ray Diffraction (XRD) that can ultimately be used to perform in vivo cancer detection. The new technique would provide a second-level screening to follow conventional mammography.

A novel microfluidic device helps detect bacteria in very low concentrations, very rapidly

**BREATHBREAK**
A new generation of energy resolved detectors that can improve the sensitivity of X-ray scattered photons for imaging.

**WHY IT’S RELEVANT**
The new information provided by EDIRD improves breast cancer diagnosis.

**MOVING FORWARD**
Evaluation of performance on human tissue; optimization of radiation dose; clinical trials of a prototype.

Conventional mammography is limited by the low contrast between the nodules to be detected and the surrounding background adipose and fibroglandular tissues. The higher the concentration of fibroglandular tissue—that is, the denser the breast tissue—the more difficult it is to detect a small lesion. This difficulty leads to both false negatives (cases where cancer goes unnoticed) and false positive diagnoses (cases where invasive biopsies are performed unnecessarily).

Scientists developed a new complementary technique based on X-Ray Diffraction (XRD) that can ultimately be used to perform in vivo cancer diagnosis. The new technique would provide a second-level screening to follow conventional mammography.

What new information does your technique provide beyond what is currently available?

The potential of XRD to improve breast cancer diagnosis had already been discussed by a number of authors in academic journals. But so far one big problem has prevented the clinical use of XRD to detect breast cancer in vivo: Because of the very low sensitivity of the system, to get the measurement needed for reliable breast cancer diagnostic tests, it would have to be performed over a prohibitively long duration.

Our strategy was to develop an imaging system based on X-ray diffraction that would overcome these challenges and could eventually be used to examine tissue in vivo. We achieved this using the semi-conductor-based spectrometric detectors, developed at CEA-Leti, that enable Energy Dispersive X-ray Diffraction technique (EDIRD), a variant of the XRD technique that uses the same X-ray sources already used in a clinical context. Moreover, this new generation of energy resolved detectors delivers the performance—in terms of energy resolution, sensitivity, spatial resolution, and throughput—necessary to measure diffracted spectra in a clinical situation.

First, we ran a simulation to show that this method is capable of detecting tumors—even in dense breasts, which often produce false diagnoses in classical mammography. Second, we conducted experiments on both plastic phantoms and mice or rats mammary glands. The results of our simulation and experiments were very promising.

**FOR MORE DETAILS**
Interview with CAROLINE PAULUS, Leti scientist

 carcine tumor detection

**COLLABORATIONS**
Institut Néel (France), Gipsa-lab (France), Inserm, CNRS, INSA, UMR1036, Biology of Cancer and Infection (France), CEA, 1036 Institute of Biotechnology of Grenoble (France)

**FOR MORE DETAILS**
Material-specific imaging system using energy-dispersive X-ray diffraction and spatially resolved CdZnTe detectors with potential application in breast imaging

Simulation study of an X-ray diffraction system for breast cancer detection
F. Marteau, C. Montmont, C. Paulus, O. Michel, and C. Paulus

**INTERVIEW**
CAROLINE PAULUS, Leti scientist
A new bio-inspired learning algorithm translates brain signals to movement of prosthetic devices

Specifically designed for ongoing, closed-loop learning, a new algorithm learns highly individualized brain signals in real time, so that motor-impaired patients can control external devices.

Brain-Computer Interfaces (BCI) allow severely motor-impaired patients to use their brain signals to control external devices, and thereby to achieve some degree of autonomy. While such systems have performed spectacularly in controlled demonstrations, putting BCI to clinical use has proven very difficult. One of the major challenges is training the signal decoder to recognize the highly individualized brain signals of the patient in question.

A fundamental flaw in conventional approaches is their reliance on data collected during open-loop recording sessions—sessions during which the patient imagines performing a task but does not witness the outcome. In contrast with closed-loop patterns (neural patterns generated when the patient actually performs the task), signals collected in open-loop learning sessions can only approximate signals generated by the patient in real life.

Another flaw in conventional approaches is that learning occurs in a separate phase, prior to real use of the BCI. As a result, the algorithm is not able to improve over time, nor is it able to adapt to inevitable changes in brain signals.

To overcome these challenges standing in the way of clinical use of BCI, a team of researchers developed an adaptive incremental learning algorithm to calibrate BCI systems in real time, as the patient goes about performing tasks.

What did you do to improve the way in which BCIs learn?

Rather than train our model in a separate open-loop session, we train our model in real time, in a closed loop. The patient starts to do something and the model learns in parallel, without any special preparation. Over time, as the patient continues to do things, the model is updated and becomes more efficient.

The high dimensional data flow using a 2-D grid of sensors is a distinctive feature of neural activity processing. While most state-of-the-art approaches for a BCI decoder identification are vector oriented, we found that multi-way [tensor] data processing could significantly improve the quality of analysis because it considers the intrinsic nature of the data under analysis. The tensor-based approaches unite the fast and efficient calculation scheme of the Recursive Exponentially Weighted Partial Least Squares (REW-NPLS) regression algorithm for high dimension multi-way [tensor] data treatment, and adaptive modeling of the complex processes in real-time conditions. The method unites the fast and efficient calculation scheme of the Recursive Exponentially Weighted PLS with robustness of the tensor-based approaches. In addition, we use a method for online estimation of the hyper-parameters, instead of the conventional offline cross-validation procedure.

The algorithm makes it possible to have a fast (just a few minutes for a degree of freedom) and intuitive learning procedure, which is crucial for clinical BCIs.

What more work needs to be done to reap further rewards from your learning algorithm?

The next challenges we intend to address are to provide enough degrees of freedom to allow severely motor-impaired patients to regain autonomy at home using chronic minimally invasive recording technology and to prepare BCI for clinical use. Our algorithm will be implemented in the ‘BCI and Tetraplegia’ clinical trial, which was approved by the French regulatory authorities and is ongoing at Clinatec.

Outside our own work, we think that our approach, which combines complex multi-modal data structures and adaptive modeling to perform real-time learning, can be applied to several other areas in healthcare, including rehabilitation to restore the lost output of the central nervous system as a result of a stroke or partial spinal cord injury, and coma diagnostics, prognosis, and progress monitoring. What’s more, our algorithm can be applied to a wide range of domains outside of neuroscience. Potential applications include video sequence analysis and adaptive monitoring of complex industrial processes.

COLLABORATIONS

CHU Grenoble Alpes (France)
CEA-List (France)

FOR MORE DETAILS

Recursive exponentially weighted N-way partial least squares regression with recursive-validation of hyper-parameters in brain-computer interface applications


© P. Joly / Leti / Clinatec scientist
A new way of estimating energy expenditure (EE) will allow an artificial pancreas to release the right amount of insulin at the right time.

**BREAKTHROUGH**
A better way of estimating EE using HR and AS data.

**WHY IT’S RELEVANT**
An artificial pancreas needs an accurate real-time estimate of EE to deliver the right amount of insulin at a given instant.

**MOVING FORWARD**
Adaptation of artificial pancreas technology to the special needs of children, adolescent pregnant women, and patients with type-2 diabetes.

The job of an artificial pancreas is to optimize insulin delivery to provide the right dose at the right instant to avoid complications, such as hypoglycemia or hyperglycemia. During and after a physical activity, the right dose depends on the amount of energy the patient is expending at the time or spent in the last few hours, a value called energy expenditure (EE).

Researchers have developed a new model that provides more accurate and highly personalized EE estimates in real time.

How did you develop your model to estimate EE in real-time?
There are a number of different approaches to estimating EE using data from non-invasive sensors. These methods work by using regression or more advanced parameter estimation methods to obtain linear or nonlinear equations from a database of data measurements taken while subjects perform various physical activities.

We developed a method that computes the intensity of the physical activity the patient is performing at a given time. When a patient performs vigorous physical activity, the model estimates EE by using only heart rate (HR), when the patient performs less intense physical activities, the model estimates EE by using linear combinations of both accelerometer signals (AS) and HR.

With your new method of estimating EE in place, what are the next steps in helping as many people as possible with the artificial pancreas?
We already have a prototype of the Diabeloop artificial pancreas, which has been in clinical trial for adults in an outpatient setting since May 2017. The manufacturer Diabeloop SA expects to launch the system right away.

**COLLABORATIONS**
CARMIEN, INSERM U1235, CERM, CRNH-Rhône-Alpes (France); Centre Hospitalier Sud-Francilien (France); CERITD (France); Diabeloop SAS (France)

**FOR MORE DETAILS**
Non-invasive assessment of deep buried flap viability with time-resolved optical monitoring: results on pigs
A.Planat-Chrétien, A.Dott, M.Perriolat, M.Berger, B.Lartient, J.L.Colli, and G.Betteg

How does your imaging technique detect oxygenation at different layers?
By detecting oxygenation at different layers of depth, time-resolved optical imaging overcomes one of the big challenges of recovery from free flap surgery.

**BREAKTHROUGH**
The first pre-clinical demonstration of the use of a time-resolved optical stethoscope to detect and characterize the oxygenation of deep flaps (1-1cm).

**WHY IT’S RELEVANT**
The ability to monitor events deep beneath a superficial diffusive layer minimizes the need for more invasive techniques.

**MOVING FORWARD**
Clinical trials: adaptation to other applications.

Surgical reconstruction using free flaps is a complex operation. A flap is taken from one part of the patient’s body and transplanted in the area of concern, using microsurgery to reconnect the vascular network. The flap is relatively thick and may include any combination of skin, fat, or muscle.

In the days following the operation, the risks of vascular occlusion are high. Consequently, postoperative monitoring of the flap is important, and it is commonly carried out by clinical examination (inspection and palpation), a procedure that is highly operator dependent. When the flaps are buried under approximately 5cm of skin, fat, and highly absorbent muscle, monitoring becomes downright impossible.

In our pre-clinical demonstration, we detected and identified both arterial and venous occlusions during post-operative recovery in 1cm deep buried flaps. We cross-validated our results with a clinical LICOX™ invasive reference that measures the partial pressure of oxygen in the tissue.

Next, what are the next steps?
Our most ambitious objective is to disseminate this instrumentation clinically in order to envisage a broad clinical validation—not only within the framework of the flap monitoring problem, but also for other applications.

To reach this objective, we are carrying out three sets of activities in parallel. One is to clinically validate the existing system for flap monitoring. The second is to use less expensive and more integrated time-resolved sensors. We are addressing this as part of an ongoing European Horizon project. And the third activity is to couple time-resolved optical imaging with complementary modalities. Bi-modal systems coupling optical and ultrasound measurements are under development at the moment. One involves fluorescent imaging and targets prostate monitoring; another targets breast cancer diagnosis.

**COLLABORATIONS**
Centre Hospitalier Annecy Genevois (France); Centre Hospitalier Ruegenheim (France); Diabeloop SAS (France).

**FOR MORE DETAILS**
Non-invasive assessment of deep buried flap viability with time-resolved optical monitoring: results on pigs
A.Planat-Chrétien, A.Dott, M.Perriolat, M.Berger, B.Lartient, J.L.Colli, and G.Betteg

Time-resolved optical monitoring to detect and identify deep flaps
A.Planat-Chrétien, M.Berger, B.Lartient, M.Henry, B.Houang, M.Perriolat, J.L.Colli, G.Betteg

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**Interview MAEVA DORON**
Leti scientist

**Highlights 03**

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**Breakthrough:** A better way of estimating integral pancreas

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**Details:** Personalization of a compartmental model for an artificial pancreas through integration of patient’s state estimation

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**Collaborations:** CEA-Leti, Univ. Grenoble Alpes, Institute for Advanced Biosciences, Centre Hospitalier Ruegenheim (CHANGE); INSEEM-UGA U11209; CNRS LIFM.509 Biophotonics/Biomedical Optics Congress, OSA Technical Digest, paper W3A.27, 2018.

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**Details:** Time-resolved optical monitoring to detect and identify deep flaps

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**Collaborations:** Centre Hospitalier Annecy Genevois (CHANGE); Proc. of the IFWS Congress, Oct. 2018.

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**Interview ANNE PLANAT-CHRETIEN**
Leti scientist

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**Details:** Non-invasive assessment of deep buried flap viability with time-resolved optical monitoring: results on pigs

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**Collaborations:** Centre Hospitalier Annecy Genevois (CHANGE); Proc. of the IFWS Congress, Oct. 2018.
Despite their excellent immunostimulating properties, virus-like particles (VLPs) still fall short as antigen delivery systems in two ways. First, they are expensive to produce. Second, they have highly conserved structures, called pathogen-associated molecular patterns (PAMPs), that stimulate the immune system, but that can lead to pathogen-induced inflammation and associated tissue damage in an uncontrolled manner.

In this context, synthetic nanoparticle-based systems have been gaining increasing interest for vaccine delivery—especially for their targeting properties. Not only do nanoparticles with diameters below 150 nm enter the lymph vessels that ultimately take them to lymph nodes, but they are also internalized by antigen presenting cells (APCs). Furthermore, nanoparticle carriers may prevent antigen proteolytic degradation—and they allow the co-delivery of antigen and immunostimulant and cross-presentation by dendritic cells (DC).

Lipid carriers, in particular, present an excellent biocompatibility profile, and they can be produced on a large scale—two features required for industrialization. To advance the state of the art, a team of scientists designed an innovative delivery system of protein antigens based on chemical grafting of the antigen onto the shell of nano-structured lipid carriers (NLCs).

What did you demonstrate about the advantages of using NLCs to deliver protein antigens? Using ovalbumin (OVA) as a study model of a protein antigen, we compared the immunogenicity properties in mice of different formulations of NLC grafted with OVA. We studied the influence of two main parameters—size (80 nm versus 120 nm) and surface charge (anionic versus cationic). We showed that all mice immunized with OVA delivered through NLC produced much higher antibody titers for all tested formulations as compared to the positive control group—mice immunized with OVA or OVA formulated in Complete Freund Adjuvant (CFA).

More interestingly, the 80 nm anionic lipid particles were the most efficient antigen carrier for eliciting both higher humoral immune response and cellular immune response, characterized by a strong secretion of gamma interferon (IFN-g). These results associated with the demonstrated non-immunogenicity of the NLC carrier by itself open new avenues for the design of smart sub-unit vaccines.

What are your next steps? A second area of research will be to validate our approach in other animal models—the immune system of mice is quite different from that of humans. Finally, our third area of research is to demonstrate that the potency with which these lipid particles induce specific immune responses is correlated with a protection against infections. That is after all, the ultimate goal of vaccines.
LETI & CELLMIC LLC TO ACCELERATE THE GLOBAL MARKET ADOPTION OF LENS-FREE DIAGNOSTICS AND BIOMEDICAL SENSING

GRENoble, France & LOS ANGELES – May 3, 2018 – Leti, a research institute at CEA Tech, and Cellmic LLC, a company dedicated to improving patient healthcare with smartphones and biophotonics, today announced that they joined forces to accelerate the market adoption of lens-free imaging and sensing techniques by growing Leti’s patent portfolio with a core patent from Cellmic.

Pioneered by Aydogan Ozcan, UCLA’s chancellor’s professor, and his research group, this patented computational lens-free imaging approach reconstructs detailed images of specimens from their holographic shadows that contain unique 3D information of samples, such as tissue sections, blood smears and cell cultures. Cellmic LLC, a UCLA spin-off, holds some of the core patents of this important computational imaging technique.

INTERNATIONAL TEAM LAUNCHES MICROFLUIDICS GROUP TO WRITE STANDARDS TO SPEED DEVICE DEVELOPMENT & MANUFACTURING

GRENoble, France – June 15, 2018 – Leti, a research institute of CEA Tech, announced today that new ISO standards on microfluidics will be developed under Leti’s initiative and guidelines.

Microfluidics involves fluid-handling devices with internal dimensions in the range of micrometers up to a few millimeters. Often referred to as lab-on-a-chip, these portable systems integrate various laboratory functions on a single integrated processor. They are expected to boost point-of-care diagnosis in fields such as health care, and immediate, onsite environmental analysis and monitoring.

LETI DEVELOPS LENS-FREE, POINT-OF-CARE SYSTEM FOR DIAGNOSING SPINAL MENINGITIS

SAN FRANCISCO – Jan. 30, 2018 – Leti, a research institute at CEA Tech, has invented a lens-free microscope technology that provides point-of-care diagnosis for spinal meningitis. Outlined in a paper presented today at Photonics West, the new technology provides immediate results and eliminates errors in counting white blood cells (leukocytes) in cerebrospinal fluid, which is required to diagnose the infection.

Spinal meningitis is an acute inflammation of the membranes covering the brain and spinal cord, which can be fatal within 24 hours. Until now, early diagnosis of the infection required an operator using an optical microscope to manually count white blood cells in cerebrospinal fluid.

MORE DETAILS:
http://bit.ly/2QNIPEs

MORE DETAILS:

MORE DETAILS:
http://bit.ly/2QO0awN

Towards industrial applications
The current power requirements of today’s large-scale computing systems are not sustainable in the long run. To address this issue, we must improve energy efficiency at a mass scale, at the device, chip, board and system levels. Nevertheless, technology must also take into account consumer demand. To meet these requirements, we must work on maximizing energy efficiency without sacrificing quality and on sustainability (recycling and reducing our use of raw materials). As shown in the following highlights, novel technologies reconcile high-performance and energy savings, offering solutions to critical global challenges.

04

Innovative Devices and Architectures for Power Efficiency

Advanced processes and techniques usher in new applications for 3D stacking

A new architecture for vision chips enables applications that require higher frame rates, lower latency, and lower power consumption

RRAM enables the bio-inspired paradigm of collocated storage and processing

An innovative start-up converter performs cold start from ambient energy alone

The next generation of phase-change memory moves towards the next generation of applications

An innovative way of implementing logical operators provides ultra low-power computing for IoT

A new wireless sensor promises to deliver the data needed to design higher performance aircraft engines

An entirely electrical manipulation of electron and hole spins in silicon may facilitate large-scale integration of qubits

A new understanding of GaN devices, a big step towards greener energy converters

Biomechanical energy harvesters that power wearable devices better than anything yet seen

Towards industrial applications
Advanced processes and techniques usher in new applications for 3D stacking

A new set of processes and techniques for 3D Sequential Integration (3DSI) proves to maintain reliability and performance at low temperature budgets.

BREAKTHROUGH
New processes and techniques that allow 3DSI without excessive degradation in reliability or performance.

WHY IT’S RELEVANT
The ultra-dense interconnects between heterogeneous devices enable architectures in which memory and processing are co-located.

MOVING FORWARD
Demonstration of a full 3D VLSI integration with a top MOSFET at 500°C; development of ultra-low thermal budget FETs: application of 3DSI to sensor interfaces.

Based on stacked layers of devices fabricated one on top of each other, 3DSI results in extremely scaled 3D contact pitch. The alignment accuracy and feature size of stacked tiers and inter-tier connections are limited only by lithographic resolution—not by bonding alignment accuracy, the limiting factor when using 3D packaging. 3DSI enables a wide range of new and improved applications and huge leaps in performance—leaps one might think of as “More Moore,” as well as those one might consider “More than Moore.”

But one obstacle preventing the industrial use of 3D stacking was that the thermal budget for the stacked layers had to be limited to preserve bottom layer performance. The standard temperatures needed to fabricate devices (beyond 1000°C) have detrimental effects on the performance of devices on the already fabricated layer. But temperature conditions during fabrication of the top level might cause a decrease in performance of the devices on the bottom. Consequently, temperature budgets have been limited to around 500°C for the devices fabricated on the top layers. However, this limited top temperature can degrade the performance and the reliability of devices on the top layer.

A team of scientists recently demonstrated a new set of processes and techniques that allow 3DSI without excessive degradation in reliability or performance. What new processes and techniques result from your recent work on 3DSI?

We found that one key process is to remove TiN native oxide prior to poly deposition. This improves top pFET reliability within a 557°C restricted thermal budget. In parallel, using SPER [solid phase epitaxy regrowth], we further reduced the thermal budget of dopant activation from 600°C for 3 minutes down to 500°C for 10 minutes.

Regarding FinFET devices, we demonstrated for the first time an activation with an innovative low temperature double SPER [DSPER]. The performance of the devices is 60% of that of the high temperature process of reference, and the low temperature thermal budget is compatible with 3DSI technology. This process uses a gate-last self-aligned contact approach, which is characterized of advanced high-performance FinFET nodes.

This type of memory-logic stack also aligns nicely with brain-inspired computer architectures, because the high via density can be used to mimic the high density of synaptic connections. The layering of successive logic and memory planes also corresponds to the structure of artificial neural networks— that is, a succession of neurons (logic or analog CMOS layers) joined by synaptic connections (memories).

Because 3DSI enables maximum connectivity between devices emulating neurons and those emulating synapses, it is particularly relevant technology for a brain-inspired ultra-high energy efficient computing cube.

Now that you’ve solved a significant set of problems that have stood in the way of 3DSI, what new research questions need to be addressed?

One area of interest is demonstrating a full 3D VLSI integrated with a top MOSFET at 500°C, with resulting performance of the top layer MOSFET equal to that at the bottom layers.

Another objective is to lay the groundwork for new directions in device optimization for applications other than traditional Von Neumann computing. For example, IoT applications or neuromorphic computing could require smaller performance devices, justifying the development of ultra-low thermal budget FETs (with thermal budgets less than 400°C), such as TTF [thin film transistor], CNT [carbon nanotube], and junction-less devices.

Still another area of interest is around sensor interfaces. 3DSI offers a large potential for sensor interfaces, enabling new options for circuit partitioning.
Hight-speed image acquisition and low latency are essential requirements of imaging applications, such as manufacturing inspection, robot control, and autonomous vehicles. The best way to enable this very quick exchange of large volumes of data between image sensors and processing arrays is to embed sensors and processors on the same chip—a vision chip.

3D stacking is recognized as a good architectural choice for arranging the components on a vision chip. But so far, all approaches based on 3D stacking have used a traditional design with column-based readout circuits, which results in a communication bottleneck.

A team of scientists has come up with a new approach: clustering massively parallel in-focal-plane data flow between pixels and the processing matrix. Each cluster embeds a small pixel matrix, readout circuits, 16 associated processing elements, and a local memory unit. This topology enables short data paths between top and bottom tiers, leading to reduced communication power consumption and increased data bandwidth. Our prototype processed up to 5500 images per second and performed 85 GOPS/watt (85 billion operations per Watt).

Because our vision chip reaches a frame rate that’s five times higher than state-of-the-art, we think our solution could open up a variety of new opportunities for image analysis systems. One area of future research is to move away from the general-purpose design we used for the initial demonstrator, and to design systems that are optimized for specific applications. A second area of work is to include three or more layers in the 3D stack, instead of just the two we’ve done in our initial work. Finally, we intend to apply artificial neural network techniques to this massively parallel hardware architecture.

A new architecture for vision chips enables applications that require higher frame rates, lower latency, and lower power consumption.

**Breakthrough**
A 3D-stacked vision chip, with in-focal-plane 3D connections, enabling high-speed video capture with low-latency digital processing.

**Why it’s relevant**
This architecture enables applications that require power-efficient image interpretation and low-latency decision-making.

**Moving forward**
Optimization for specific applications; design of a three-layer stack; incorporation of artificial neural network approaches.

One area of future research is to move away from the general-purpose design we used for the initial demonstrator, and to design systems that are optimized for specific applications. A second area of work is to include three or more layers in the 3D stack, instead of just the two we’ve done in our initial work. Finally, we intend to apply artificial neural network techniques to this massively parallel hardware architecture.

A massively parallel approach to the design of vision chips eliminates the communication bottleneck between image sensors and processing units.
RRAM enables the bio-inspired paradigm of co-located storage and processing.

The demonstration of two key attributes of RRAM contribute to the birth of a new computing paradigm, where storage and processing are inseparable.

BREAKTHROUGH
A better understanding of the trade-offs when using RRAM for TCAM, and a demonstration of how at least one RRAM-based unsupervised learning algorithm actually performs better when there is a certain amount of synaptic variability.

WHY IT’S RELEVANT
It’s a step forward towards a new computing paradigm that would halve both the computing time and the energy consumption for applications with large data sets.

MOVING FORWARD
Creation of C-TCAM and research into the impact of conductance variability on other neural network topologies.

An innovative start-up converter performs cold start from ambient energy alone

Becuase of their limited lifetime, batteries are not a suitable power source for wireless sensor nodes or applications based on implantable devices. For these low-power applications, a better approach is to use a completely autonomous system that harvests ambient energy to enable “deploy and forget” sensor nodes capable of operating for several years without maintenance.

What new research questions arise as a result of this new understanding of the behavior of the system for TCAM and as a platform for unsupervised learning?

One next step is to extend RRAM-based TCAM by adding computational capabilities. This would result in computational TCAM, or C-TCAM, and it builds on the current planar research work at Leti around C-RRAM.

Another next step is to study the impact of conductance variability on larger neural networks and on new neural network topologies, such as recurrently connected long short-term memory (LSTM) and gated recurrent unit (GRU). With that better understanding, we can design, implement, and refine the unsupervised learning technique on prototypical RRAM-based hardware accelerators.

The second part of our work stems from the fact that a RRAM-based TCAM solution will be smaller and will consume less power than SRAM-based TCAM, which opens up new possibilities with applications, such as neuromorphic engineering.

For this second phase, we explored how RRAM devices can be used to reproduce brain-like activity in neural-circuit models. Here we demonstrated that a neural network that learns is based on neural networks and learns through the Spike-Time Dependent Plasticity algorithm (an unsupervised learning algorithm) not only holds up well against noise, but it also performs better at learning when there is a certain amount of synaptic variability. In biological learning systems we see a very similar behavior in the presence of noise.

What happens is that RRAM conductance variability increases the range of synaptic values that are explored during the learning process. Moreover, when RRAM conductance variability is increased, the system is able to operate under lower-power programming conditions.

COLLABORATIONS
Centre de Nanosciences et de Nanotechnologies (France)
CNRS, Université Paris-Sud (France)
University of Ferrara (Italy)

FOR MORE DETAILS
Experimental investigation of 4-bits RRAM arrays: programming conditions suitable for TCAM.

Role of synaptic variability in resistive memory-based spiking neural networks with unsupervised learning.

A 15-mV inductor-less start-up converter using a piezoelectric transformer for energy harvesting applications.
The next generation of phase-change memory moves towards the next generation of applications

**Leti** is gaining a deep understanding of the physical and chemical phenomena governing phase change material behavior to target high performance embedded memory devices.

Phase Change Memory (PCM) is the most promising candidate among emerging non volatile memory technologies. It provides a variety of promising features such as fast read and write access, excellent scalability, potential, and high endurance. PCM is already a product reality in the Storage Class Memory market; the next short-term goal is to make it ready for the embedded one. In order to target embedded applications, PCM technology is challenged to meet strict specifications such as high temperature reliability, low programming current and high yield—meaning that it is almost impossible for a single memory cell to fail.

What is your strategy to overcome technological limitations and related challenges of future phase-change memories?

At Leti, we are working on the next generation of PCM devices by identifying and addressing their different technological and material challenges. Engineering of innovative phase change alloys allows PCM to retain information up to high temperatures (>200°C) targeting compatibility with automotive specifications and the soldering reflow thermal profile. Nevertheless, programming current reduction in PCM devices is also necessary to achieve high-density memory products. Our developments show that improvement of the thermal efficiency of the PCM device is a key reducing power consumption. For this purpose, the engineering of the confined structure of the PCM cell as well as the fabrication of the chalcogenide based heterostructures offer the most promise to achieving a real breakthrough in PCM performances.

For instance, we first demonstrated that innovative nano-engineered germanium disulfide / antimony telluride (GeS2/Sb2Te3) PCM can lead to an improved thermal confinement and to a decreased volume of the active material embedded in an amorhous insulating matrix. Moreover, Van der Waals-layered GeTe/Sb2Te3 superlattices (SLs) are explored at Leti in order to develop low-power, innovative interfacial PCM (iPCM) devices. We demonstrated for the first time that the crystalline and local atomic structure of such SLs is highly dependent on the tellurium (Te) concentration. This result leads to new understanding of the physics of the resistive transition occurring in such new PCM systems.

We expect also that heterostructures such as multilayers (MLs) made of periodically stacked nanometric amorphous phase change layers will enable a higher energy efficiency thanks to a strong anisotropic thermal conductivity and a higher thermal stability resulting from the volume confinement of the active material at the nanoscale.

These developments will make PCM suitable for low power applications like IoT, enabling large size arrays and 3D architectures already used in stand alone applications, such as Crossbar arrays.

What future applications do you see for PCM?

The next step is to introduce PCM in the embedded automotive market, while in parallel addressing the high endurance required for both static and dynamic random access memory (SRAM/DRAM) replacement. The current PCM research has an impact on several applications, such as multilevel storage, hybrid devices combining resistive and magnetic memories, logic devices, and even devices for THz pulse detection.

Moreover, PCM paves the way towards mimicking the behavior of brain elements such as synapses to reproduce biological architectures present in the nervous system, with the design of so-called neuromorphic computers. It will allow us to develop compact and low-power computing systems, which could process information like the brain through learning, adaptation, and probabilistic association.

The new physics offered by this unique class of materials allows also to explore new applications such as opto/photonic circuits and sensors, thermoelectric modules, spintronic devices, etc. It requires multidisciplinary efforts and collaborations involving teams from different fields: materials science, theoretical physics, simulations, deposition engineering, physico-chemical characterization, process and integration engineering, electrical characterization and innovative design.
An innovative way of implementing logical operators enables ultra low-power computing for IoT

Combining mechanics and electronics to drastically improve energy efficiency, a new computing paradigm will have a big impact beyond just IoT. Its impact will reach a number of other application areas, including high temperature computing, radiation tolerant systems, and high reliability memories.

B

ecause of the tradeoff between leakage and active power dissipation of any semiconductor technology, CMOS technology is now knocking up against a power efficiency ceiling. No conventional techniques will move power efficiency beyond that threshold. CMOS scaling won’t work—neither will better electronic gate control nor alternative FET structures. It has become clear to the scientific community that only a paradigm shift will provide a dramatic reduction in the power dissipation of the fundamental digital operations that power the modern information age.

Researchers propose a new logic operation, called contactless adiabatic logic (CAL), which breaks the inherent tradeoff between existing leakage and conduction losses by removing the need for electrical contact.

What are the important aspects of the CAL approach?

In the CAL approach, rather than use resistive technology, the elementary device is a four-terminal variable capacitance (VC) element. For example, a micro-relay VC has two voltage terminals to control the capacitance across two others. The most interesting property of this new logic family is that no electrical contact occurs during logic operations, which means the family is inherently immune to leakage losses.

To experimentally prove the concept of CAL, we implemented VCIs using a well-known MEMS structure: the comb drive actuator. To have a 4-terminal element, we designed two mechanically coupled, electrically isolated, comb drives. As opposed to other MEMS based computations, such as micro-relay, no mechanical contact is needed. In this way CAL improves the mechanical reliability and scalability potential, because there is no adhesion force. By driving adiabatically a VC pipeline—with gradual information coding and erasure—we recovered 99% of the stored mechanical and electrical energy during Boolean operations.

We also showed how to arrange VC elements to create all combinational logic gates (AND, XOR, and so on), a pipeline structure, and more complex digital operations (N-bit adders, Fredkin gates, and so on). In addition, we proposed comb-driven structures to perform combinational operations using a single device. Furthermore, volatile and non-volatile memories are available to build a processor structure.

What new research questions are raised as a result of CAL?

We’ve proven that it’s possible to implement a CAL-based processor based on comb drive MEMS. The next step is to process a thinner comb drive—a 100 nm lithography node—to achieve the same energy dissipation as with state-of-the-art FET-based logic.

We are also studying other implementations outside of MEMS to increase the operation frequency, which is currently limited by a mechanical time constant and stored energy. We will conduct further research to explore the limits of this technology when applied to nanoscale devices, especially electromechanical devices.

In adiabatic logic Boolean states are coded with pulses, instead of electrical levels, which means that entirely new digital architectures have to be designed. More research is needed on this topic, which so far is addressed in only a few published articles.

COLLABORATIONS

ESIEE (France), LIRMM (France), University of Notre Dame (USA)

FOR MORE DETAILS

Adiabatic Capacitive Logic: a Paradigm for Low-power Logic

G. Pillonnet, H. Tariq, and S. Houri

CEA-Leti, Tech. Univ. Delft


Contactless Four-terminal MEMS Variable Capacitor for Capacitive Adiabatic Logic

A. Galisultanov, Y. Perrier, H. Samadi, M. El-Sanadily, and G. Pillonnet

CEA-Leti, Université Paris-Est, ESYCOM, ESIEE Smart Materials and Structures, vol.17(8), July 2018

A new wireless sensor promises to deliver the data needed to design higher performance aircraft engines

A new breed of sensors allows engine designers to collect data from parts of an aircraft engine that were previously unmeasurable.

Interview

GAL PILONNET

Leti scientist

BREAKTHROUGH

The world’s first energy-autonomous sensor system that operates in severe environments.

WHY IT’S RELEVANT

This ruggedized sensor system makes it possible to optimize the performance of aircraft engines.

MOVING FORWARD

Achieving a higher technology readiness level and reducing the size of the micro-turbine and antenna.

A few aircraft engines must undergo extensive tests under high temperature and vibration levels before they are certified. During this testing phase, the engines are equipped with pressure, temperature, and strain sensors, which are connected by cable to a central unit.

To design the next-generation aircraft engine with reduced fuel consumption and lower maintenance costs, engine designers need data that can only be collected by deploying sensors onto components that are difficult to access or onto rotating elements, such as fan blades, the engine’s logistics of handling and routing cables make this virtually impossible without dropping engine performance.

One solution is to use energy-autonomous wireless sensing nodes (WSNs). But this solution requires an energy-autonomous system that operates in an environment of high temperature, high levels of vibration, and rotating elements. No such WSN has existed until now.

To ensure reliability in a harsh environment, we developed a dedicated hermetic packaging for the electronics, including connections for wiring an optional battery and sensors. What’s more, to allow the system to withstand future operating temperatures (higher than 250°C), we broke new ground by developing a specific version of the package with a new ceramic material and a new installation.

What new research questions have to be addressed to further benefit from the system you’ve demonstrated?

Technology readiness level (TRL) is a key issue to address with ASIC. We designed a new version of the circuit, including new features, such as non-volatile storage capability, which is mandatory for industrial partners. Evaluation towards higher temperature, above 250°C, is another area to explore.

As for the micro-turbine, the future challenge is to further downsize the harvester, to less than 2.5 cm in diameter, while maintaining the start-up speed and a high enough electrical output power to supply the WSN. Furthermore, aging tests need to be carried out to guarantee very long-term reliability of the device—especially for the moving parts, such as bearings.

COLLABORATIONS

SAFRAN Aircraft Engines, SAFRAN Electronics & Defense, SAFRAN Tech (France), KYOCERA (Japan)

FOR MORE DETAILS

A robust and versatile, -40°C to +180°C, 8Sps to 15Sps, multi-power source wireless sensor node for industrial applications


CEA-Leti, SAFRAN Electronics & Defense

Proc. of the Symposium on VLSI Circuits, pp.C310-C311, June 2017

© DR

Interview

BERTRAND GOMEZ

Leti scientist

Highlights O.4
An entirely electrical manipulation of electron and hole spins in silicon may facilitate large-scale integration of qubits.

**BREAKTHROUGH**

Experimental demonstration of a device geometry that could enable all-electrical electron spin control; a theoretical workaround to the speed versus stability trade-off.

**WHY IT’S RELEVANT**

Our work supports perspectives for large-scale integration of many qubits, which will be required for universal gate-based quantum computers.

**MOVING FORWARD**

Evaluation of the up scaling potential of silicon spin qubits; development of an SOI-based cryo-CMOS for classical control electronics of the quantum core; investigation of QEC-compatible architectures.

Silicon spin qubits have recently emerged as a promising approach to quantum computing, notably thanks to their compatibility with the state-of-the-art technologies the semiconductor manufacturing industry has spent several decades perfecting. However, one challenge is that, as compared to holes (i.e. the absence of electrons), electrons in silicon have an intrinsically weak spin-orbit coupling (SOC).

A team of researchers has advanced the state of the art with an experimental demonstration of electric-dipole, spin-valley resonance mediated by intrinsic SOC in a silicon double quantum dot (QD). How did you overcome the problem of weak SOC intrinsic to electrons in silicon? We are not the first to overcome this problem, but our solution comes at no overhead costs in terms of process complexity or design. One previously known way is to put a gate on top of the electron spin and use a magnet somewhere in the vicinity to create a magnetic field gradient. When you agitate your electron within that magnetic field gradient, it will perceive an oscillating magnetic field, which causes the spin to rotate. That works, and it’s a popular approach in experiments involving just a few qubits. But having to periodically integrate magnets to create a gradient for every other spin is not really compatible with large arrays of spin qubits.

What we found out is that there is something about the geometry of the device we prototyped. The confinement is asymmetrical. We have a rectangular cross section of our nanowire, and we press the confinement of the electron into one of the corners. That breaks its mirror symmetry, which causes a non-negligible spin orbit coupling term to arise.

Thanks to this device geometry, we were able to observe electrically mediated spin transitions with electrons in silicon. That’s the first experimental observation of electric dipole spin resonance (EDSR) of electrons in silicon without the use of an auxiliary magnet.

What ideas do you have about overcoming the trade off between how fast you can manipulate an electron spin and how stable it is over time? Given what we found experimentally, we came up with a theoretical mode of operation, in which we can toggle between a regime that is electrically addressable and one that is not. When we are in SOI it means that our device rests on top of a buried layer of silicon dioxide, and we can use this back interface as a spin gate. Using the back gate we can change the vertical confinement of the electron and break or restore its symmetry, and hence the sensitivity of the spin to the electric field.

The significance of our work is that first we managed to allow manipulations without having to integrate microstraps or periodically integrate magnets. That’s a step towards large-scale integration, because it reduces the overhead for integrating many qubits. The second point is that using the scheme I just described, you may actually improve the figure of merit of the number of operations you can perform before an error occurs. That goes a long way towards reducing the overhead, because if you don’t have to detect errors as frequently, you don’t need to have as much circuitry for correcting the errors.

What further research will build on the advances you’ve made in silicon spin qubits? Through our research, we’ve shed light on SOI [silicon-on-insulator] devices, which we implemented by a straightforward adaptation of a nanowire FET process flow. Our first area of research is to keep learning how the characteristics and geometry of these prototypes result in various manipulation and readout schemes for electron and hole spin qubits, some of which are enabled—or enhanced—by the additional lever that is the back gate.

The second area of research is in the context of cryo-CMOS for control electronics. Power dissipation close to the qubits is a major challenge; and our work puts high performance, low power operation back within reach, despite the combination of steepening sub-threshold slopes and rising threshold voltages at low temperature. Working on SOI has had some huge benefits, because of the back gates. We can leverage the fact that we’re able to lower the operating voltage, whereas on other technological platforms, it’s not possible—you don’t have access to the back gate.

And the third area of research is around finding other types of device architectures that would retain some qualities of the ones we’re investigating now, but that would be different in terms of connectivity and choice of materials. In contrast to our prototypes, they would start looking less like transistors, and more like some tailor-made devices that fit specific applications. That is topologically more compatible with the implementation of quantum error correction (QEC) codes for large-scale fault-tolerant computing.

**COLLABORATIONS**

C.E.A.-INAC (France), CNRS-Institut Néel (France), Université Grenoble Alpes (France)

**FOR MORE DETAILS**

Electrically driven electron spin resonance mediated by spin-valley–orbit coupling in a silicon quantum dot


All-electrical control of a hybrid electron spin/ valley quantum bit in SOI CMOS technology

A new understanding of GaN devices, a big step towards greener energy converters

New research debunks one theory and raises a new set of questions about conduction mechanisms of GaN heterojunction diodes.

Breakthrough

Demonstration that a power GaN heterojunction diode acts as a pure quantum tunneling diode in its on state, at room temperature and higher.

Why it’s relevant

Power GaN heterojunction technologies offer the potential of efficient, high frequency and high power density converters—an appealing promise in an energy-hungry world.

Moving forward

Research into using GaN heterojunction devices for quantum tunneling, application to other device architectures and process bricks.

Compared to silicon or silicon carbide devices, gallium nitride (GaN) devices lead to lower conversion losses at higher frequency, and are therefore excellent candidates for use in greener energy converters. But many questions still remain unanswered about the behavior of GaN at the material and device level, when applied to power electronics.

A team of scientists advanced the current understanding of certain conduction mechanisms of GaN heterojunction diodes, debunking one theory and raising a new set of questions.

What research strategy led you to demonstrate previously understood properties of GaN heterojunction diodes?

There were two key aspects of our strategy. The first was to make a connection between GaN-based heterojunctions and MOS [metal oxide semiconductor] contacts. This analogy offered a new vision of the III-N [AlGaN/AlN/GaN] system, and it allowed us to use the rich mathematical and physical toolbox developed in the framework of silicon MOSET.

The second important element of our strategy was to use quantum mechanical formalism to describe electronic transport. Known as Landauer formalism, this approach takes into account the probabilistic nature of electron emission at a microscopic level in a natural and general way.

Using this strategy we showed that the heterojunction diode acts as a pure tunnel diode in the on state at room temperature and higher. This revelation contrasts with the widely held Schottky diode designation found in literature. We demonstrated that the Schottky diode designation incorrectly models the transport mechanism, and leads to erroneous interpretations.

What new areas of research do you expect to arise from the work you’ve done?

We are looking into the possible use of GaN heterojunction devices that can draw more potential out of quantum tunneling. It may be possible to fabricate tunnel junctions of outstanding quality, which would impact a number of applications, including the design of aggressive and high frequency GaN converters and ICs, and rectennas, which harvest energy from electro-magnetic waves.

One of the biggest challenges standing between wearable devices and the mass market is power. Recharging the battery is impractical—and asking users to do so reduces the appeal of wearables in general. Consequently, researchers have turned their attention to power generators that harvest energy from the environment.

What techniques did you use to draw energy from the human body?

We investigated two approaches for biomechanical energy harvesting. The first is an AA-battery-sized inertial electromagnetic generator that converts the impact of footsteps into energy. We designed and optimized a prototype device that generates power densities over 800µW/cm³—so reduces the appeal of wearables in the near future?

Current biomechanical energy harvesters, including our two prototypes, are rigid, sacrificing comfort for efficiency. The next step is to move to more malleable devices.

Biomechanical energy harvesters that power wearable devices better than anything yet seen

Researchers take a big step towards enabling wearables to run entirely on energy generated by the body.

Breakthrough

Two biomechanical energy harvesters that exhibit the highest power densities ever reported.

Why it’s relevant

Efficient biomechanical energy harvesters enable fully autonomous smart wearable devices.

Moving forward

Improving the comfort of the devices and enabling in vivo bio-energy harvesting.

In each case, we combined the energy harvester with a power management circuit to supply autonomous accelerometers and temperature sensors using Bluetooth Low Energy (BLE) data transmission. Our work paves the way for Body Area Sensor Systems for leisure or sporting activities.

What research questions need to be addressed in the near future?

Now that you’ve demonstrated the feasibility of two approaches to harvesting bio-energy, what are your next research questions? It is pressure sensitivity that would be more comfortable for the user. The good option to explore is to get energy through the triboelectric effect, the transfer of electrostatic charge. A second good option is to use flexible piezolectric materials, such as PVD [piezoelectric polymer polyvinylidene fluoride].

Another interesting research area is around developing in vivo biomechanical energy harvesters for use with implanted devices, such as pacemakers.
**LETI AND CMP ANNOUNCE WORLD’S FIRST MULTI-PROJECT WAFER SERVICE WITH INTEGRATED SILICON OxRAM**

Oxide-Based Resistive Ram Memory Platform
Development for Backend Memories
To Offer Non-Volatility Associated with Embedded Designs

GRENoble, France – Aug. 2, 2018 – Leti, a research institute at CEA Tech, and CMP, a service organization that provides prototyping and low-volume production of ICs and MEMS, today announced the integrated-circuit industry’s first multi-project-wafer (MPW) process for fabricating emerging non-volatile memory OxRAM devices on a 200mm foundry base-wafer platform.

**STMICROELECTRONICS AND LETI DEVELOP GAN-ON-SILICON TECHNOLOGY FOR POWER CONVERSION APPLICATIONS**

- Cooperation to develop and industrialize advanced power GaN-on-Si diode and transistor architectures
- Process technology, benefiting from the results obtained in the IRT Nanoecs program, will be transferred from Leti’s 200mm R&D line to an ST-operated 200mm-wafer pilot-line, operational by 2020

Geneva, Switzerland, and Grenoble, France – September 24, 2018 – STMicroelectronics (NYSE: STM), a global semiconductor leader serving customers across the spectrum of electronics applications, and Leti, a research institute of CEA Tech, today announced their cooperation to industrialize GaN (Gallium Nitride)-on-Silicon technologies for power switching devices. This power GaN-on-Si technology will enable ST to address high-efficiency, high-power applications, including automotive on-board chargers for hybrid and electric vehicles, wireless charging, and servers.
Interacting Efficiently and Reliably with Complex Systems in the Digital World

Global digitalization is producing high volumes of information. Miniaturized sensors, IoT devices, mobile applications, social networks and other web data generators and processors converge to create smart, complex, adept systems. In the following highlights, we look at new possibilities for 5G network deployment, using 3D spatial sound to help the visually impaired, advancing NEMS-based mass spectrometry, creating nanosensors for bent or compressed surfaces, a new antenna that increases the capacity of cellular networks, and ways to improve cyber security.

A series of experiments demonstrates the difficulties of implementing cryptographic security IoT networks

An analysis of four use cases provides a new understanding of design tradeoffs in 5G networks

Leti’s block-filtered OFDM opens new possibilities for 5G networks

A better readout scheme advances the state of the art of NEMS-based mass spectrometry

New techniques for fabricating nanosensors enable large-scale production of flexible sensitive surfaces

Scaled down obstacle detection technology to liberate the visually impaired

New transmitarray antenna technology boosts the potential of millimeter wave communication

Towards industrial applications
A series of experiments demonstrates the difficulties of implementing cryptographic security IoT networks

Interview

JACQUES FOURNIER
Leti scientist

A team of researchers recently ran experiments that uncovered weaknesses in some of the most prominent approaches used to secure IoT networks.

BREAKTHROUGH
Demonstration that PBC is vulnerable to side-channel attacks, and that the best countermeasures won’t work.

WHY IT’S RELEVANT
The experiments show that, so far, there is no efficient way of using cryptography to secure an IoT network.

MOVING FORWARD
New research focused on finding new countermeasures to defend against side-channel attacks on PBC-based IBE schemes.

S
ecuring devices in an IoT application presents at least three big challenges. The first is that the devices are out in the field, and are relatively easy to access physically. The second challenge is that the device has constrained computing power and operates on a battery, so the cryptographic algorithms that run on a large server are not necessarily appropriate for the small thing in the field. The third challenge is that because there are a huge number of devices, procedures for IoT key initialization must scale linearly (or better).

PKI is a good way of distributing asymmetric key pairs as long as the number of users remains relatively small. But because its underlying method for key initialization scales exponentially, PKI won’t work for IoT. To initialize the keys of n devices, exchanges of the order of n-squared are required—a prohibitively large number of exchanges when billions of devices are involved.

An alternative approach to key initialization is identity-based encryption (IBE), which scales linearly. With IBE, rather than require a server to generate a key-pair based on a certificate (as is the case with PKI), encryption key pairs are generated as a function of the identity of the device. Identity could be an email address, a serial number, or some other unique value associated with the device.

Performing IBE through pairing-based cryptography (PBC) is widely viewed as an attractive solution to securing IoT devices. But researchers have now demonstrated that implementations of PBC are vulnerable to attacks—and that the currently proposed countermeasures won’t do the job.

How did you experimentally demonstrate the vulnerabilities in PBC-based IBE?

Schemes for using side-channel attacks to break PBC have been discussed in the research literature, along with potential countermeasures to those schemes. But until now, these schemes and associated countermeasures were mostly explored theoretically, with very little experimentation.

Here at CEA-Leti we have the facilities to test these theoretical methods of attacks and also their countermeasures. So our objective was to run experiments to evaluate the feasibility, and practicality, of such attacks—and on the flip side, to evaluate the efficiency of the proposed countermeasures.

The first scenario we evaluated was the use of side-channel attacks against Tate pairing running on off-the-shelf IoT devices to recover the secret key used during decryption in an IBE scheme. We achieved a ten-times gain, compared to the best results reported in the literature so far, in the number of side channel traces needed to carry out an entire attack (100 instead of 2000). This was based on correlation power analysis (CPA).

We then investigated the feasibility of a new side-channel approach, called a “horizontal attack,” against a PBC implementation and showed that, with this approach, only one side-channel curve is needed to perform the attack—far fewer than the 200 traces needed with the classical CPA.

In summary, we proved through experiments, not only the feasibility of these attacks, but also exactly how one of these attacks might occur. We then turned our attention to one of the proposed countermeasures to see if they would hold up.

This countermeasure is based on a technique called point randomization [aka “masking”]. At each execution of a pairing calculation, the public point is combined with a new random value in such a way that the attacker has no straight forward way of determining the real values used during the pairing calculation, and therefore cannot recover the secret key through statistical analysis.

We devised an attack, based on a chosen message approach, where, in spite of the presence of the randomization, we can look for collisions in the measurements of electromagnetic traces, and derive from those collisions the secret value used. We implemented this countermeasure in our Tate pairing implementation and experimentally validated the feasibility of this new attack.

What are the next steps in trying to secure IoT networks?

We have demonstrated that a side-channel attack against PBC is possible even on a single side-channel trace, and that point randomization is not an efficient countermeasure against side-channel attacks. We are now working on finding new countermeasures, such as new masking methods that are resistant to our collision-based attack.
An analysis of four use cases provides a new understanding of design tradeoffs in 5G networks

Four application scenarios help researchers explore the relative advantages of different millimeter wave (mmWave) network configurations and different mobile edge computing (MEC) architectures.

**BREAKTHROUGH**

Analysis of four 5G mmWave deployment examples, exposing the relative advantages of different architectures.

**WHY IT’S RELEVANT**

An improved understanding of use cases helps guide decisions on 5G technology and standards.

**MOVING FORWARD**

Investigation of new mmWave frequencies and proactive distributed caching for MEC.

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The standards and technological choices of 5G networks are driven by the rich set of new applications they are designed to support. These applications have stringent network requirements, including ultra reliability, ultra-high bandwidth, and low, predictable latency.

To shed light on the relative advantages of some of the different potential 5G architectures and technologies, a team of researchers from five different countries on two continents employed the technique of use case analysis. Not only did they develop models that took into account existing usage patterns, they also ran simulations—and even a proof of concept.

**How did you choose the four use cases and what are some of the peculiarities of each case?**

The four use cases we chose were scenarios we expect to be relevant to 5G users from around the world. These scenarios all involved some combination of the 28 GHz frequency band, which is planned for use in 3GPP (3rd Generation Partnership Project) new radio, and the 60 GHz band, which is an unlicensed band currently used by WiGig [IEEE801.11ad]. They also involved mobile-edge computing.

The first case was millimeter wave-empowered fixed-wireless access and moving hotspots. We ran a proof-of-concept of this scenario at the PyeongChang Winter Olympics. We used mmWave for a wireless backhaul to locations in Europe, and for multi-beam transmissions and adaptive beam forming to provide mobile hot spots in buses near the games.

The second case was 60 GHz unlicensed indoor access combined with mobile edge computing (MEC) to enable ultra-high speed content download with low latency. Mobile users are expected to transfer large amounts of video content in places, such as homes and offices—and even railway stations or airports. Augmented reality will also be used inside places such as stadiums and shopping malls.

The third case was mmWave mesh network to be used as a micro radio access network (μ-RAN), for cost-effective backhauling of small-cell base stations in dense urban scenarios. In such a setting, traffic distribution is not uniform from one place to another—and there is a great difference in volume from one time of day to another.

Finally, the fourth scenario was mmWave based V2X [vehicular-to-vehicular] and V2X [vehicular-to-everything] communications system, which enables automated driving by exchanging HD [high definition] dynamic map information between cars and RSUs [roadside units]. The current requirements for automated driving call for data rates of 1 Gbps per link, end-to-end latency of less than 10 milliseconds per link, and a communication range of 150-300 meters.

Given the use cases you’ve exposed, what are the most important research areas in the near future? For 5G and beyond, mmWave and MEC will each play an important role for a diverse set of applications that require both ultra-high data rate and low latency communications. Perhaps the most important such application—and one that’s frequently discussed in the press—is automated driving.

To help overcome the challenges of providing ultra-high data rates and low latency, we are investigating new millimeter wave frequencies for high capacity communications. In this same context, we are also researching proactive distributed caching—not only content caching, but also computational caching. This will greatly enhance the performance of mobile edge computing.

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**COLLABORATIONS**

5GChampion Consortium (Belgium, Finland, France, Germany, Korea)

5GChampion (France, Germany, Italy, Japan)

5GMiEdge Project (France, Germany, Italy, Japan)

FOR MORE DETAILS

5GCHAMPION – Disruptive 5G technologies for roll out in 2018

B.Vautherin, T.Deleu, B.Vautherin, Y.Kim, M.Merluzzi, M.Mueck, C.A.Pärssinen, A.Pärssinen, Y.Kim, and E.Calvanese Strinati

Enabling Effective Mobile Edge Computing Using Millimeterwave Links

S.Barbula, E.Ceci, and E.Calvanese Strinati

Sapienza University of Rome, DIET, CEA-Leti

Proc. of the IEEE International Conference on Communications Workshops (ICC), pp. 367-372, May 2017
A new variant of orthogonal frequency division multiplexing (OFDM) meets the requirements of 5G air interfaces, and paves the way for multiservice applications.

Leti’s block-filtered OFDM opens new possibilities for 5G networks

**Interview**

DIMITRI KITENAS

**Leti scientist**

**A new variant of orthogonal frequency division multiplexing (OFDM) meets the requirements of 5G air interfaces, and paves the way for multiservice applications.**

**Flexible and efficient use of non-contiguous unused spectrum in heterogeneous mobile network deployment scenarios is one of the key challenges facing 5G network designers. To maximize the use of spectra, 5G networks must have the smarts to map various services to the most suitable combinations of frequency and radio resources available.**

These requirements are not satisfied by the waveform currently considered the main candidate for 5G networks, cyclic prefix orthogonal frequency division multiplexing (CP-OFDM). And they are only partially satisfied by alternative multicarrier waveforms, such as universal filtered multicarrier (UFMC) and filter bank multicarrier (FBMC).

Leti scientists have introduced a new waveform that might do the trick. A new quasi-orthogonal waveform called Block-Filtered OFDM (BF-OFDM) that, with only a slight increase in complexity, overcomes most of the weaknesses of CP-OFDM with respect to spectral localization and performance in asynchronous scenarios.

**What makes BF-OFDM different?**

Spectral localization and multi-user performance are better than those of OFDM, while similar equalization methods can be implemented of OFDM, while similar equalization methods can be implemented.

BF-OFDM is highly flexible and is configured by setting filter bank FFT [fast fourier transform] size, carrier bandwidth, OFDM pre-coding FFT size, and CP size parameters. It is scalable and different configurations can be used to optimize performance for a given indicator—for example, to provide greater resistance in high mobility situations, or to provide quicker response when low latency is required. The scalability of our waveform paves the way for future multiservice-applications.

**What are the next areas of research on BF-OFDM?**

We are working on two new areas. The first, which has already begun, is to run 5G field trials with multiservice transmission and a protocol on top of BF-OFDM.

The idea is to propose flexible MAC [medium access control] scheduling for quality of service constrained transmissions, taking into account the properties of the BF-OFDM waveform, such as robustness to asynchronous and very low out-of-band leakage, and enabling a fair coexistence with other BF systems using the same bands.

**COLLABORATIONS**

CNAM (France)

**FOR MORE DETAILS**

Block-Filtered OFDM: A new promising waveform for multi-service scenarios


**Conference**

Proc. of the IEEE International Conference on Communications (ICC), pp.1-6, May 2017

**5G multi-service field trials with BF-OFDM**


**Conference**

Proc. of the IEEE Globecom Workshops (GC), pp.1-5, Dec. 2017

**A better readout scheme advances the state of the art of NEMS-based mass spectrometry**

**Interview**

GILLES SICARD AND GERARD BILLIOT

**Leti scientists**

**A compact heterodyne self-oscillator analog front-end enables very high-resolution spatial mapping through a dense array of CMOS-integrated NEMS.**

**The integration of NEMS structures with commercial CMOS technology makes it possible to produce high-density mass spectrometry systems, consisting of more than 1000 devices that can observe relatively large areas with atomic level resolution. But to meet the requirements of single particle mass sensing applications, the system needs to track all the resonators and in real time—with two modes per resonator.**

**COLLABORATIONS**

Direction générale de l’armement (France)

**FOR MORE DETAILS**

30-to-600MHz simultaneous dual-mode heterodyne oscillator targeting NEMS array gravimetric sensing applications with a 3000g mass resolution

G.Gourlat, M.Sansa, P.Villard, G.Sicard, G.Jourdan, I.Ouerghi, D.Miras, CEA-LETI

**Conference**


**Interviews**

**HENRIK ANDERSSON**

**University of Linköping (Sweden)**

**FOR MORE DETAILS**

A future-frame approach to optical wireless communication in 5G mobile networks

A frame-based architecture for multi-service communication in 5G mobile networks

A.Furuskar, S.Ashah, G.Kranc, A.Elsayed, R.Camacho, D.Barker, M.Jalali

**Conference**

Proc. of the IEEE International Conference on Communications (ICC), pp.1-5, May 2016

**Article**

Proc. of the IEEE, 105, (11), pp. 2572-2587, Nov. 2017

**Interview**

**VICTORIEN PETERSSON**

**Tampere University of Technology (Finland)**

**FOR MORE DETAILS**

A new phase reference technique for millimeter wave mmWave MIMO systems

V.Petersson, J.Akimov, J.Österberg, J.Hartikainen

**Conference**

Proc. of the IEEE 86th Vehicular Technology Conference (VTC), pp. 1-5, May 2018

**Interview**

**CHRISTOPHER RENNER**

**Technical University of Munich (Germany)**

**FOR MORE DETAILS**

Low-latency OFDM for 5G mobile networks


**Conference**

Proc. of the 2019 IEEE 87th Vehicular Technology Conference (VTC-Fall), pp. 1-5, May 2019

**Article**

Proc. of the IEEE Journal on Selected Areas in Communications (JSAC), 37, (4), pp. 921-936, Apr. 2019

**Interview**

**ANDREAS NUSSBAUM**

**University of Munich (Germany)**

**FOR MORE DETAILS**

A promising solution for 5G: dynamic subchannel allocation using dynamic resource assignment

A.Nussbaum, V.Petersson, J.Akimov, J.Österberg, J.Hartikainen

**Conference**

Proc. of the 2019 IEEE 87th Vehicular Technology Conference (VTC-Fall), pp. 1-5, May 2019

**Interview**

**RAFIK SULAIMAN**

**University of Halmstad (Sweden)**

**FOR MORE DETAILS**

5G Massive MIMO based on dynamic resource allocation

R.Sulaiman, A.Nussbaum, V.Petersson, J.Akimov, J.Österberg, J.Hartikainen

**Conference**

Proc. of the 2019 IEEE 87th Vehicular Technology Conference (VTC-Fall), pp. 1-5, May 2019

**Article**

Proc. of the IEEE Access, 7, pp. 14760-14770, Mar. 2019
New techniques for fabricating nanosensors enable large-scale production of flexible sensitive surfaces

A process that scales up to 8-inch wafer sizes—and that relies on an ordinary membrane peeling technique and a handful of simple technological steps—opens up new possibilities for mechanical sensing applications on surfaces that may be bent or compressed.

BREAKTHROUGH
A simple and scalable process for fabricating sensitive surfaces made of flexible capacitive piezoelectric sensors using vertically aligned gallium nitride wires.

WHY IT’S RELEVANT
A robust process for making flexible sensitive surfaces enables seamless integration into objects and large-scale deployment of mechanical sensing devices that can be bent and compressed.

MOVING FORWARD
Optimization of the whole system, scaling of the processes, and design of low consumption driving electronics aimed at increasing the technology readiness level and enabling industrial production.

Nanomaterials, such as piezoelectric gallium-nitride wires (PGW), have a number of properties—flexibility, low cost, and high mechanical robustness—that make them very attractive building blocks for designing devices that can operate in both compression and bending modes. What’s more, these materials derive enough energy from the physical action they measure to be self-powered.

Based on the results of PGW-related fundamental studies carried out at CEA, researchers recently demonstrated a new scalable process for fabricating sensing devices that are thin and flexible enough to be integrated into or onto objects. These devices can operate in compression mode (where deformation along the vertical axis is directly induced by the applied force) and in bending mode (where the strain along the principal axis of the wire is indirectly determined by the Poisson effect).

How have you advanced the state of the art for developing flexible sensitive surfaces?

The process we developed is a simple and scalable fabrication process for thin, flexible capacitive piezoelectric sensors using vertically aligned PGW in a PDMS (polydimethylsiloxane) matrix. This process is well suited for system integration and industrial compatibility, relying on an ordinary peeling technique and requiring very few and simple technological steps. Furthermore, the process is scalable to 8-inch wafer sizes.

We also implemented a state-of-the-art multiphysics and multi-scale model to map the potential into a PDMS-PGW based capacitive structure under a compression constraint of several nanometers per square micrometer. We used this model to demonstrate how a number of parameters—including wire morphologies, density, orientation, and encapsulation—impact on the degradation of potential and on device variability. We showed that voltage output level and sensitivity increase as a function of the wire length—and that, in contrast to horizontally aligned devices, a conical shape is not necessary for generating potential in vertically aligned devices.

Remarkably, we also found that PGW are very robust with regards to high temperatures—inhomogeneous intrinsic polarization is not lost upon heating. However, we found that heating does cause combined pyro/piezo-electric effects, which is an area that needs to be investigated.

What more can be done to achieve your ultimate goal of industrial transfer of the technology?

To ready the technology for industry, we are taking a global system approach, using scalable processes and a robust overall system design. We’re now working on implementing the associated flexible nanoelectronics for larger sensor matrices that adapt to curved surfaces and map deformations induced by touch, impact, constraints, and so on. We also plan to trial prototype devices in two maritime applications: wearable sensors to monitor the equipment worn by sailors, and sensors that monitor various aspects of a sail’s behavior.

A third research area is to improve our model to take into account piezoelectric effects and to extend the model to a complete system of distributed pixels/sensors.

COLLABORATIONS
CEA-LETI (France)

For more details:
Flexible capacitive piezoelectric sensor with vertically aligned ultralong GaN wires A. El Kacimi1, F. Pauliac-Vaujour1, and J. Eymery2

1CEA-LETI, CEA, INAC-MEM, CNRS, France.
2Centre de Nanosciences et de Nanotechnologies, University of Versailles-Saint-Quentin-en-Yvelines, France.

Piezo-potential generation in capacitive flexible sensors based on GaN horizontal wires A. El Kacimi1, F. Pauliac-Vaujour1, and J. Eymery2

1CEA-LETI, CEA, INAC-MEM, CNRS, France.
2Centre de Nanosciences et de Nanotechnologies, University of Versailles-Saint-Quentin-en-Yvelines, France.

Scaled down obstacle detection technology improves the lives of the visually impaired

Combining readings from different sensor types, a small-scale obstacle detection system uses 3D spatial sound to communicate potential danger to the visually impaired and blind.

BREAKTHROUGH
Integration of several range sensing technologies, along with software to model the surrounding area, in a small, low-power, lightweight device.

WHY IT’S RELEVANT
We’ve dramatically improved obstacle detection capabilities for visually impaired people.

MOVING FORWARD
The development of new services based on information extracted from the occupancy grid.

Among the 185 million visually impaired or blind (VIB) people in the world, only 5% are considered fully autonomous in their daily lives. The pressing need to liberate the VIB is one of the reasons the white cane was chosen by the Integrated Smart Spatial Exploration System (INSPEx) consortium as the first use case for the spatial exploration systems the consortium was formed to develop. A white cane helps the VIB by scanning the surrounding area for obstacles or orientation marks.

While multi-sensor spatial exploration systems are well understood when applied to vehicles, making similar technology work on a white cane presents a number of new challenges. The first set of challenges is that, like any IoT solution, the system must operate with constrained processing and it must use very little power. An additional set of challenges is that the system must communicate three-dimensional information using only sound.

A team of scientists recently overcame a number of these challenges, enabling a new generation of white canes, which in turn will improve the lives of the visually impaired and blind. The VIB, flexible spatial exploration system developed for this project was a miniaturized and portable lower power system, based on multiple sensor types. What big steps did you take towards scaling down spatial exploration systems for use in a white cane?

State-of-the-art electronic white canes do not properly perform in all weather conditions for a large typology of obstacles, because they use only one kind of range sensor technology. No single kind functions in all conditions. This problem was solved in spatial exploration systems designed for use in autonomous vehicles by combining multiple subsystems including LiDAR (light detection and ranging), radar, ultrasound, and optical. Data from these subsystems is merged with vehicle orientation and navigation subsystems using software components, such as SigmaFusion®.

But the hardware in these systems is heavy and power hungry—and the software requires high computational capabilities, including floating-point arithmetic. Source of our big challenges was to implement SigmaFusion® technology on a constrained portable computing platform.

Our system uses a notion we call “the safety cocoon,” which is the area around the person where we want to detect potential objects that might present a danger. Within the safety cocoon we set up an occupancy grid, which is a way of modeling the objects and their locations in three dimensions. We use 3D spatial sounds to communicate information about the object in the grid to the user, through headphones worn outside the user’s ears.

What new areas of research do you expect to spring from your work on a scaled-down multi-sensor spatial exploration system? This project offers the opportunity to take SigmaFusion® one step further. The occupancy grid can be analysed, taking into account application-specific requirements to produce high-level information that is directly understandable and useful to the user. One potential application would be path planning for either a person or a terrestrial or aerial robot.

COLLABORATIONS
CEA-LETI (France), Cork Institute of Technology (Ireland), G.E. Sains (France), University of Manchester (UK), University of Namur (Belgium), ON Semiconductor Sensing (USA), STMicroelectronics (France), Tyndall National Institute (Ireland)

FOR MORE DETAILS:
INSPEx: Design and integration of a portable/wearable multisensor spatial exploration system L. Eymery1, J. Pauliac-Vaujour1, 2, J. Foucault1, 3, J.-M. VanGyseghem1, 4, J. Barrett1, 5, S. Lesecq1, 3, J. Fisek1, 2, R. Barančík1, 3, M. Van Geem1, 4, C. O’Murchú4, C. Jackson6, T. Leturcq7, T. de Geyter5, D. McCaffrey7, D. O’Durch7, and A. Mathewson4.

Proc. of the Design Automation & Test in Europe Conference & Exhibition (DATE), pp.746-751, March 2017

Interview
SUZANNE LESEQ
Leti scientist

Interview
EMMANUELE PAULIAC-VAUJOUR
Leti scientist

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International conference on inte...
New transmitarray antenna technology boosts the potential of millimeter wave communication

A new design advances the state of the art for transmitarrays, antenna technology poised to increase the capacity of cellular networks by one or two orders of magnitude.

Interview

ANTONIO CLEMENTE
Leti scientist

Millimeter wave (mmWave) frequency bands (from 30 to 300 GHz) may provide a ten- to hundred-fold increase in the capacity of current cellular networks, enabling backhaul links that could provide a peak capacity of between 10 and 25 gigabits per second, connecting access points to the core network through line-of-sight RF communication.

Transmitarray antennas, which are composed of a focal antenna or array illuminating a flat-array of several hundreds or thousands of elements, are an extremely attractive antenna technology for use in mmWave frequency bands. Thanks to their specific spatial feeding architecture, transmitarray antennas have one clear advantage over reflectarray antennas and classical phased arrays: They don’t suffer from blocking effects and losses in the feeding network. Transmitarray antennas are not only attractive technology for cellular networks. They are also attractive for use in the Internet of Space, serving as relatively low-cost and high-gain antennas with the electronically beam-scanning capabilities needed to develop the future terminal for the SATCOM-on-the-move applications in the Ka-band.

Researchers recently demonstrated several highly efficient wide-band transmitarrays with fixed-beam and electronically beam-scanning capabilities that advance the state of the art.

What did you do to advance the state of the art for transmitarrays? We demonstrated a 20×20 element fully reconfigurable circular-polarized transmitarray, based on a 1-bit reconfigurable unit-cell operating in the Ka-band (27.4 – 31.7 GHz). We used the sequential rotation technique with a random rotation scheme in order to optimize the beam-steering capabilities.

The experimental results exhibit very good performance, in agreement with simulations. Specifically, we demonstrated an antenna power efficiency of 99%, a broadside gain of 20.8 dBi in circular polarization, and a beam-steering capability of ±60°.

Finally, we introduced a planar focal array to reduce the antenna focal distance and to improve its compactness by about 40%. To our knowledge, this work presents the first demonstration of a circularly polarized, reconfigurable transmitarray in Ka-band, with beam steering and polarization switching capability.

What new research areas follow naturally from your demonstration of a new design for transmitarrays? One new area of research is around increasing the competitiveness of the proposed fixed-beam technology. This includes developing ultra-low profile and/or integrated architectures and demonstrating a transmitarray up to sub-THz frequencies with ultra-wide band behavior (i.e. around 250 – 325 GHz).

Another area of research is around developing an electronically steerable transmitarray with multi-beam capabilities. This is required to increase the communication efficiency in the future 5G systems and SATCOM applications.

What did you do to advance the state of the art for transmitarrays? We demonstrated a 20×20 element fully reconfigurable circular-polarized transmitarray in Ka-band with beam scanning and polarization switching capabilities. L.Petit1, A.Clemente2,3,4, L.Dussopt1,2, E.Sauvage5, A.Petit5, and P.Phulpin5

“Université Grenoble Alpes, CEA-LETI, IETR, University of Rennes 1, Direction Générale de l’Armement (France)”

Leti

“CEA-LETI, Direction Générale de l’Armement (France)”


Wideband linearly polarized transmitarray antenna for 60-GHz backhauling

C.Jourdan1, A.Clement1, M.Huchard1, J.Migneret1, C.Barbier1, L.Dussopt2, and L.Petit5

“CEA-LETI, Direction Générale de l’Armement (France)”

IEEE Transactions on Antennas and Propagation, Vol.65(5), March 2017

COLLABORATIONS

IETR, University of Rennes 1 (France)

Direction Générale de l’Armement (France)

Radiall (France)

LETI, TRANSDEV AND IRT NANOELEC ANNOUNCE PILOT PROGRAM TO ASSESS NEW PERCEPTION SENSORS FOR AUTONOMOUS VEHICLES

GRENOBLE & ISSY-LES-MOULINEAUX, France – July 5th, 2018 – Leti, a research institute at CEA Tech, Transdev, a leading global provider of mobility services, and IRT Nanoelec, an R&D center focused on information and communication technologies (ICT) using micro- and nanoelectronics, today announced a pilot program to characterize and assess LiDAR sensors to improve performance and safety of autonomous vehicles.


LETI AND VSORA DEMONSTRATE 3GPP NEW RADIO (5G NR) ON MULTI-CORE DIGITAL SIGNAL PROCESSOR

Collaboration Designs a First Version of the 5G NR Release 15 Physical Layer

GRENOBLE & PARIS, France – SEPT 4, 2018 – Leti, a research institute of CEA Tech, and VSORA, which specializes in multi-core digital signal processor (DSP) design, today announced they have demonstrated the implementation of 5G New Radio (5G NR) Release 15 on a new DSP architecture that can dramatically reduce time to market of digital modems.


EU-SOUTH KOREAN PROJECT WILL DEMONSTRATE 5G SYSTEM PROTOTYPE AT 2018 WINTER GAMES

• 5GCHAMPION Teams Built World’s First State-of-the-Art Terrestrial Wireless Communication System, Including Disruptive Satellite Communication
• Symposium with Leading Companies and Researchers Scheduled in Seoul on Feb. 23

PYEONGCHANG, Korea – Feb. 12, 2018 – Leti, a research institute of CEA Tech, today announced that the European and South Korean project, 5GCHAMPION, will demonstrate the world’s first 5G platform from Feb 20-22, during the 2018 Winter Games.

MORE DETAILS: http://bit.ly/2LcEANi


• 5GCHAMPION Teams Built World’s First State-of-the-Art Terrestrial Wireless Communication System, Including Disruptive Satellite Communication
• Symposium with Leading Companies and Researchers Scheduled in Seoul on Feb. 23

CEA-LETI MIDDLEWARE WILL BE CORE OF FOG PLATFORM FOR DECENTRALIZED CLOUD-TO-EDGE AI

DECENTER Project to Integrate IoT, AI, the Cloud, Edge, Fog Computing and Smart Contracts Tied Together with Secure Blockchain in ‘New Ecosystem’ for On-Demand Edge Computing

GRENOBLE, France – Oct. 25, 2018 – Leti, a research institute at CEA Tech, today announced that its sensNact Internet of Things (IoT) middleware will be the core of a platform under development in an EU-Korean project that will empower emerging artificial intelligence (AI) applications with on-demand computing at the edge of networks.


Towards industrial applications
Highlights

06

Strategic Programs

Quantum Computing
Artificial Intelligence at the Edge
Integrated LiDAR
Digital 5G
Quantum Computing

Semiconductors and quantum physics have provided the physical support and the theoretical paradigms for the explosion of information technologies and the construction of a digitally connected society. But semiconductor-driven information technologies have arrived at a tipping point where transistor scaling is no longer the cornerstone of performance improvement and economic growth, as we now face fundamental issues such as power consumption and data privacy management. To tackle these challenges, entirely new technological solutions must be developed.

There is an increasing hope that a new generation of quantum technologies can extend the digital platform and make it safer, more energy efficient, more sensitive, and simply more powerful. Previously untapped quantum effects in customized systems and materials are paving the way for a second quantum revolution, relying on the most counter intuitive features of quantum mechanics—single objects can be in different states at the same time (superposition) and can be deeply connected without any direct physical interaction (entanglement).

The scientific discoveries and the promises of early applications have resulted in a first generation of scientific roadmaps for the three pillars of quantum technologies: computing, communication, and sensing. Leti and its partners are very well positioned to set the scientific-driven targets, address the associated grand engineering challenges, identify the applications and build the industrial and business ecosystem that will benefit from the developments in quantum technologies.

In Grenoble, Leti is at the heart of a very unique ecosystem: with highly skilled science teams and resources, it benefits from both its local and global partnerships. Our teams are exploring quantum sensing for magnetometers, among other applications, providing greater accuracy than the current technologies in a variety of fields. Additionally, Leti in collaboration with CNRS and the CEA fundamental research division are working towards the development of a quantum processor based on silicon technologies that will support at least one hundred quantum bits (this project has been granted a prestigious ERC Synergy funding). And finally, Leti is leveraging its integrated silicon photonic platform to demonstrate integrated transmitters for entangled photons, working towards an unbreakable quantum internet and safe machine-to-machine communications.

Maud Vinet
Quantum Program Director

Artificial Intelligence at the Edge

The interest in this 60-year-old research domain, was strongly renewed in 2012. Impressive results from deep learning techniques applied to image classification, natural language translation or game strategy, have shown that Artificial Intelligence will be a game changer in many domains.

There are several reasons for the surge in AI: algorithmic breakthroughs in the artificial neural network, increase of GPU computing power, and the massive amount of data available in the cloud. While traditional computing requires manual coding from humans, deep learning techniques allow for computers to actually learn from the data and provide novel solutions.

Today, the potential of AI is valued across all economic sectors and industries including manufacturing (e.g. defect detection), big data (e.g. advertising), and human-machine interfaces (e.g. Google Home or Amazon Echo). AI proposes a novel approach to solve complex optimization problems.

At Leti, researchers have developed neuro-inspired hardware IP, combining a new design paradigm and advanced technologies (e.g. spike coding and OxRAM non-volatile memory). Furthermore, Leti is exploring innovative ways to build smart sensors, from transducers and analog and digital filtering, to sensor fusion and AI-based decisions. Our long-term objective is to gather these building blocks end-to-end and bring AI to embedded systems.

Frédéric Heitzmann
AI Program Director
Mobility is at a crossroads. Creating a safer, smarter, and more mobile future is a major challenge for our modern society. Autonomous mobile systems that integrate environment-perceiving sensors are being used to innovate across a variety of applications including automated mobility, high-performance computing and connectivity, and automotive-grade safety and security. One of the most critical ones is certainly LIDAR - Light Detection and Ranging system.

LIDAR is based on the detection of reflected laser illumination and can generate an accurate three-dimensional image of the surroundings, providing critical real-time information of ever-changing environments. Most notably, carmakers are leveraging LIDAR capabilities as a key component in the development of safe, self-driving vehicles as well as in Advanced Driver Assistance Systems (ADAS).

Despite global investment in these technologies, significant challenges remain. Diverse technologies, components and architectures must be considered in order to bring cost-effective, robust and reliable products to market. This is especially true in the growing segments of machine vision and mobility.

The keys of such development lie in the combination of innovative components fused with intelligent data processing delivered by LIDARs and others sensors. Leti's state-of-the-art expertise in photonics, heterogeneous technologies and integration enable mass production of LIDARs at low cost. For example, Leti demonstrated a fully integrated silicon photonics Optical Phased Array capable of steering the laser light beam. Leti is also involved in the development of highly sensitive Single Photon Avalanche Diodes (SPADs) using advanced CMOS technology. On the algorithm side, Leti developed very innovative data processing approaches enabling efficient fusion of measurements from multiple perceptual sensors including lidars, radars, vision sensors, etc. Through the co-innovation of microelectronics/photonics technologies and software algorithms, Leti has the capability of developing a low-cost chip-scale LIDAR—making Leti a key player in the field.

Leti is working on a consolidated technological roadmap and the tools to respond to partner demands in LIDAR systems. Innovations are expected in the emitter, receiver and data processing with embedded artificial intelligence. The future of LIDAR requires sensors to be at the chip-scale to attain the low cost requirements and volume potential of not only the automotive market but also other fields of application such as robotics and industry 4.0.

François Simoens
LIDAR Program Director

Digital 5G

5G should be deployed by 2020 and will bring a multitude of new challenges to industry, opening an era of cyber-physical systems at a global level. The leading requirements of 5G integrated systems will come from verticals such as automotive, smart cities, utilities and smart industry. Next-generation broadband and IoT access will accelerate 5G deployment and open new ranges of digital services.

5G networks will require ultra-dense connectivity to ensure sufficient quality of service, given the expected exponential increase in users and machines. Zero latency response, needed for critical applications and desired for most, will depend on the proximity of computing resources to network nodes.

The complexity of future 5G connectivity will benefit from self-organized smart networks. Consequently, most 5G nodes will be linked to distributed network management systems that will collect and analyze contextual cyber-physical information. 5G network paradigms will call for a close cooperation between infrastructure and applications and new standards will introduce unprecedented challenges, including new levels of complexity in the different building blocks. Naturally, microelectronics will play a key role in the integration of 5G systems.

François Simoens
LIDAR Program Director

Lionel Rudant
5G Program Director

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5G Program Director

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François Simoens
LIDAR Program Director

Lionel Rudant
5G Program Director
Collaborations
Grenoble: A World-Class Innovation Ecosystem

Leti, a technology research institute of CEA, is located in Grenoble in the French Alps. Leti is at the heart of Grenoble’s Innovation campus for Advanced New Technologies (Cedant) which brings together leading fundamental and applied research laboratories, a high-tech industrial environment, and unique European research infrastructures such as the most intense neutron source in the world (at the Laue-Langevin Institute or ILL), Europe’s largest synchrotron X-ray source (ESRF), an outstation of the European Molecular Biology Laboratory (EMBL) and the French Institut de Biologie Structurale (IBS).

Over the years, Grenoble has become the home of many leading higher education and research institutions, and of major high-tech companies who have moved into the area or been created to become part of our dynamic and synergistic environment. This year, CEA, INRIA, Minalogic, Grenoble-Alpes University, and the Regional Council launched MinaSmart: a regional program to prepare the next generation of highly competent researchers in nanoscience and nanotechnology.

The Nanoelec Technological Research Institute brings together research centers and companies working in the area of Information and Communication Technologies to develop new technologies that will benefit industry, and in particular SMEs, in all activity sectors. The different members of the IRT Nanoelec benefit from world-class R&D teams and infrastructure, and work together to develop new products and applications for tomorrow’s IoT.

One recent program is POWERGAN - a new competitive key enabling solution for energy efficiency and power density. Another important component of the Nanoelec IRT’s mission is to put in place new training programs to prepare the next generation of highly competent researchers in nanoscience and nanotechnology.

The academic and research community of Grenoble (named “Université Grenoble Alpes: University of Innovation”) was awarded the Initiatives for Excellence (IDEX) award by the French government. The IDEX award recognizes scientific and pedagogical excellence and a passion for innovation and entrepreneurship. Leti contributes to three important projects: cybersecurity, new technologies for connected objects and their components, and quantum engineering aiming at creating an ecosystem for quantum technologies connecting science, the humanities and enterprise.

Grenoble’s breathtaking natural environment and active student life also make it one of the best places to study in France. The city welcomes over 62,000 students each year from 140 different countries. Many students interested in gaining hands-on experience in innovation come to Leti to work on challenging technological research projects and benefit from top-notch clean-room and characterization facilities.

Leti: An International CARNOT Institute

Leti is one of France’s 38 Carnot Institutes. The Carnot label of excellence is granted to French public research centers dedicated to fostering innovation with industrial partners. Carnot institutes skillfully renew their scientific and technological knowledge and conduct collaborative research that improves the competitiveness and growth of their business partners.

Carnot institutes engage in upstream research projects and ambitions scientific collaborations with the best research teams worldwide. They also establish highly professional research partnerships with industry, from start-ups and SMEs to large companies, with the ultimate goal of creating value through innovation.

Leti is carrying out challenging multidisciplinary research in areas such as, for example, next generation phase change memories and disruptive 3D monolithic integration processes to pave the way towards neuromorphic circuits, extremely sensitive small pitched infrared imagers for breakthrough medical applications, the development of new models to design optimized and disruptive photonic devices, low power optical networks-on-chip for future HPC applications, and the design and integration of high data rate, low power systems to enable Tb/s wireless communications.

Many of these projects are being carried out with first-rate research partners worldwide. Some of our international partners include Stanford University, University of Chicago, Boston University, MIT, Caltech, KTH, ETH Zurich, EPFL, FZ Jülich, HKUST, Keio University, Nil and Tsukuba University, to name a few. In the 2017-2018 period, Leti researchers also carried out joint projects with and at Stanford, MIT, and University of Toronto thanks to Enhanced Eurotalents* and Carnot mobility funding.

Working with some of the best teams in the world in our core research areas is contributing to strengthen Leti’s scientific excellence and develop an open mindset.

To find out more about the Carnot institutes, look us up at http://www.instituts-carnot.eu

*Enhanced Eurotalents is a four-year (2014 to 2018) Marie Skłodowska-Curie Action offering one to three year international mobility fellowships for researchers and post-doctoral students.
In 2004 Nokia and Thales established III-V Lab in France under the status of “Economic Interest Group” (GIE). “The name III-V comes from the fact that we assemble elements from the third and fifth columns of the periodic table of elements,” explained Jean-Pierre Hamaide, president of III-V Lab. “Using these elements, we create new materials that don’t exist in nature and that have unique features essential to microelectronic and photonic devices. The key application areas of interest to Nokia and Thales are telecommunications, defense, and security.”

For the first several years of its existence, III-V Lab had deep knowledge of epitaxial growth, processing, design, and testing of III-V materials, but was missing deep expertise in integration on silicon. To fill that gap, CEA became the third member in 2010, providing not only new skills, but also access to their 200mm and 300mm silicon facilities.

“Leti brings their knowledge and mastery of silicon,” said Hamaide. “That’s the key element from the fourth column of the periodic table that allows us to integrate the new materials we’ve created with circuits and micro-systems. Silicon brings the industrial platform that makes these materials usable on an industrial scale, at the heart of systems.”

III-V materials and technologies are essential for the future generations of microelectronic and photonic devices. By combining III-V and silicon, III-V Lab is able to reach a level of integration and performance that was previously impossible.

III-V Lab has advanced the state of the art in two main areas. The first is in silicon photonics for next generation telecommunications networks. III-V Lab demonstrated widely tunable laser sources with record wavelength tuning range over 75nm. These lasers were fabricated by heterogeneous integration of III-V materials on silicon.

The second area where III-V Lab advanced the state of the art was in microdisplays for Augmented Reality and Virtual Reality systems. By integrating GaN-based microLED arrays on a CMOS active matrix, they demonstrated state-of-the-art results.

III-V Lab helps ensure its activities are used in the real world by forming partnerships and by creating startups. In 2015 III-V Lab created a startup called mirSense that markets sensors that use mid infrared to detect gases, such as CO2.

Jean-Pierre Hamaide
Chairman & Managing Director III-V Lab (France)

Imec and CEA-Leti join forces on Artificial Intelligence and Quantum Computing

During the state visit of President Emmanuel Macron in November 2018, Imec and CEA-Leti — two world-leading research and innovation hubs in nanotechnologies for industry — announced the signing of an agreement that lays the foundation of a strategic partnership in the domains of Artificial Intelligence and Quantum Computing to strengthen European strategic and economic sovereignty and underline Europe’s ambition to take a leading role in the development of these technologies. The collaboration should result in the delivery of a digital hardware computing toolbox that can be used by European industry partners to innovate in a wide variety of application domains – from personalized healthcare and smart mobility to the new manufacturing industry and smart energy sectors.

Leti adds silicon to III-V Lab’s photonics and microelectronics

In June of 2018, Fraunhofer and CEA-Leti, signed an agreement to join efforts to optimize the mutual use of their complementary technologies and initiate an ambitious new plan to bring innovation to their national industries and Europe at large. The agreement involves topics concerning silicon based technologies for the next generation technologies and products including design, simulation, unit process and material development as well as production techniques as well as More than Moore and packaging technologies.

Fraunhofer and Leti to collaborate on silicon based technologies

In March of 2018, CEA and ZiangJiang Lab, a leading Chinese research institute, signed a comprehensive collaborative agreement to set up specific joint projects in research areas of strategic importance to the ecosystem of China and France. Leti’s role in the agreement is to explore with the Chinese counterpart opportunities to collaborate in various technical fields including communications, semiconductor technologies, and biotechnologies - addressing topics such as advanced design and manufacturing, low power technologies (FD-SOI in particular), system integration, digital 5G technology, internet of things (IoT), beyond Moore, medical devices, and brain inspired computing.

Chinese Lab – ZiangJiang and CEA-Leti to work together in various strategic technical fields

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Leti and Centre Hospitalier Universitaire (CHU) Grenoble Alpes have collaborated for more than 10 years on a number of projects, including the European project Biocapan and several French projects, with an exclusive focus on fighting diabetes.

Two themes have guided their research. The first theme is to use cell therapy to combat diabetes by reimplanting Islets of Langerhans, which are irregularly shaped patches of endocrine tissue located within the pancreas. Leti developed a method for encapsulating these islets to prevent them from being destroyed by the body, and to allow them to perform their normal function of producing hormones. This technology has undergone pre-clinical trials.

The second theme is to treat type 1 diabetes by using a control loop to automate the delivery of insulin. This led to the establishment of a research lab, then to a startup company called Diabeloop. This technology has been tested on a large group of patients; and Diabeloop received its CE marking in November, 2018, paving the way for commercial release of the new product.

“What attracted me most about Leti was their enthusiasm for testing innovative technological solutions for treating diabetes,” said professor and CHU practitioner Pierre-Yves Benhamou. “They didn’t have direct experience with diabetes when we first started collaborating, but they learned a lot about it along the way. To the benefit of the partnership, Leti scientists brought in new methods of research and original approaches.”

Testimonials

Leti and CHU Grenoble Alpes combat diabetes through innovation

Leti, INAC, and Néel lay the foundations for large-scale quantum computing

CEA-Leti, CEA-INAC, and CNRS Néel have taken important steps towards their overarching objective of demonstrating the feasibility of a quantum computer based on silicon MOS VLSI technologies. In 2016 the partners demonstrated the world’s first proof-of-concept of a single hole qubit fabricated within a CMOS transistor integration flow. More recently, they demonstrated a single-shot read-out of electron spin at a speed below 1ms with a fidelity of 99%

The three laboratories have the right mix of skills and resources in physics and engineering to address the challenges of large scale quantum computing. While the partners share a common background in physics, and are familiar with the quantum language of “kets” and “bras” (column vectors and row vectors), each of the three institutes brings something unique to the collaboration. Leti provides know-how in vertical CMOS integration at nanoscale, INAC contributes an understanding of the physics of electrons in CMOS devices, and Néel brings its expertise in electron spin qubit manipulation in semiconductors.

“The co-location of our consortium is very important,” said Dr. Tristan Meunier of CNRS-Néel. “The three institutes are all situated in Grenoble, just five minutes from one another by bike. This proximity results in a friendly environment, and plenty of synergy. The partners benefit from a rich ecosystem of academic and industrial entities, including a local expertise in cryogenics and industrial semiconductor manufacturers.”

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Leti and the Lyon Institute of Nanotechnology (INL) began collaborating on integrating photonics on silicon in 2000. The partnership was formalized by an agreement signed in December 2012, and renewed and extended for a period of five years in December 2015.

The overarching goal of the collaboration between Leti and INL is to integrate photonics and electronics on the same chip – that is, to achieve the convergence of optical and CMOS fabrication routes. The technological objective is to demonstrate that complementary photonic materials can be added to the silicon microelectronic fabrication platform. This work is expected to impact a range of applications, including tele- and data-communications, environmental and biomedical sensors.

As a result of their collaboration, INL and Leti demonstrated a number of basic functions that enable the integration of photonics on silicon. These functions are essential for implementation of electronic-optical chips, where different blocks of circuitry exchange information via optical paths. One notable outcome of the partnership was pioneering work in integrating micro-laser sources on silicon. And most recently, the partners obtained broadband sources (“super-continuum”) in the mid-infrared range, opening up possibilities to interrogate integrated optical circuits of chemical or biological sensors.

Having already demonstrated the relevance and the feasibility of this convergence, the partners are now proceeding along two major lines: readying the technology for industrialization and tailoring the technology to a larger range of applications by developing an appropriate set of tools and features.

“Leti has not only had very solid technological platforms for a long time,” said Dr. Xavier Letartre of INL, “but they also know how to use and manage those platforms. At INL we are able to test an idea very quickly, but in a form that is far from true implementation. Leti, on the other hand, takes the same technology and demonstrates how it can be industrialized. Leti provides the all-important path from the laboratory to industry.”

Leti and the Institute of Electronics and Telecommunications of Rennes (IETR) began collaborating in 2004 to push the envelope on the design of antenna technology. Then in 2006, the partners began to focus their attention on transmitarray antennas, experimentally demonstrating several prototypes. In particular, they developed three electronically steerable transmitters, one at X band and two at Ka band. Today these prototypes are considered state of the art in the international literature.

The partners also demonstrated state-of-the-art fixed beam prototypes up to 80 GHz; and they developed fixed beam technology at 60 and 80 GHz, which CEA-Leti transferred to the French company Radiall.

More recently, the partnership has focused on a project that aims to develop innovative, high gain and broadband antenna technology at millimeter wave frequencies (30 – 300 GHz). Within this project, research was conducted along two dimensions. The first involved the development of technology to form an electronic beam. The second was to demonstrate an ultra-low-profile architecture.

Working together in national and European projects, and co-supervising several PhD students, the partners produced a number of notable results. They designed and demonstrated a fixed-beam transmitarray in a printed circuit board (or metal only), and with dual-band and dual polarization at Ka-band. They also designed and demonstrated three electronically reconfigurable transmitarrays, low-profile transmitters, and passive transmitarrays up to 80 GHz. To analyze and optimize the transmitarrays, the partners developed a set of numerical tools.

When asked about the partnership, professor Ronan Sauleau of IETR said, “Leti’s strength in research and development stems from their capacity to address scientific challenges from all angles. Researchers at Leti can manage all aspects of a project, from start to finish, applying all their skills and scientific know-how, and all their knowledge of how things work in industry.”

There’s more to come. The partners began a new ANR project, called NEXT5G, at the end of 2018 and they plan to propose a new ANR ASTRID project in 2019.

Xavier Letartre
CNRS Research Director
at Lyon Institute of Nanotechnology (France)

Ronan Sauleau
Professor at Institut d’Electronique et de Télécommunications de Rennes (France)
Leti and KTH, a lasting collaboration in photonics

"Leti is a leading player in a range of fields, from electronics to photonics—and to manufacturing," said Professor Srinivasan Anand of KTH Royal Institute of Technology. "A combination of state-of-the-art facilities and competence in these fields, and Leti’s strong track record in innovation and extensive industrial network, make Leti a very valuable collaborative partner." 

Leti and KTH have cooperated on European projects, including the European networks of excellence (Epixnet) from 2005 to 2008, and Nanophotonics for energy efficiency (N4E) from 2010 to 2015. The N4E project promoted new cooperation in the fields of solid state lighting and competence in these fields, and Leti’s strong track record in innovation and extensive industrial network, make Leti a very valuable collaborative partner.

The project focused on III-nitride light emitting diodes—not on the emitting devices themselves, but on add-on thin layers for light extraction and color conversion. The thin layers enhance the emitted power by limiting the amount of light trapped in the device, and/or by converting the emitted blue light into light of a longer wavelength. These functionalities are essential for emerging micro display technology, and for high luminance and coplanar tri-color emission as key parameters. Leti and KTH mainly used soft imprinting and nano-patterning in this project.

Leti provided expertise in photonic design and optical characterization, some III-V materials, and wafers of nitride LEDs for final evaluation of the photonic layers. KTH brought its expertise in soft lithography techniques, in III-V materials and fabrication, electromagnetic modeling, physics, and characterization of semiconductor nanostructures.

"I recall that as our first approach, we were investigating a procedure to in-fill nanoparticles from solution into silicone molds and then transfer print the patterns," recounted Srinivasan. "While this works well, it invariably resulted in etch-gaps at the pattern / LED surface, which is a no-go for light extraction. One of the memorable moments was a late evening meeting where we asked ourselves, ‘What if we work the other-way around—that is, use the mold directly to press the nanoparticles solution pre-coated on the target surface?’"

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Helene Larin and the Grenoble Nanosciences Foundation. The chair of excellence was formed at Leti and co-funded by Lanef and the Grenoble Nanosciences Foundation. The chair of excellence was awarded to professor Paul Nealey of the University of Chicago.

A pioneer in the field of DSA for over 20 years, Paul Nealey developed breakthrough technology for directed self-assembly of block copolymer films on lithographically defined chemically nano-patterned surfaces. Scientists at Leti have also been performing leading research on DSA for a number of years, but from a different angle. Among other things, the Leti scientists developed a template grapho-epitaxy DSA process where we use traditional lithographic techniques to create a template that can then be used to direct assembly of nanostructures.

"The main project we’re working on is developing processes where we use traditional lithographic tools and processes to make chemical patterns, and then use those patterns to direct assembly of the block copolymers to assemble patterns that are useful for semiconductor manufacturing.”

"Leti has one of the clean room facilities and expertise that sit at the interface of academic research and industry," Nealey said. "You can develop a technology that looks good on the laboratory scale, but there’s still a lot of work to do to bring that technology to a state where it can be useful for a manufacturing setting. There are very many places in the world where you can conduct that kind of research. Leti is one of them.”

Chair of Excellence aims to industrialize DSA of block copolymers

Directed self-assembly (DSA) may be the most promising strategy for high-volume, cost-effective manufacturing of nanoscale integrated circuits of the future. DSA takes materials that self-assemble to spontaneously form nanostructures at the molecular scale, and integrates them with traditional semiconductor manufacturing to enhance the performance of materials and / or processes, often at reduced cost. So far, no single institution or collaborative group has been able to bring together all of the scientific and technological elements needed to address the issues standing in the way of the industrialization of DSA. To meet and overcome these challenges, a chair of excellence was formed at Leti and co-funded by Lanef and the Grenoble Nanosciences Foundation. The chair of excellence was awarded to professor Paul Nealey of the University of Chicago.

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"We are using self-assembling block co-polymers, which are materials that spontaneously form structures at the 3 to 50 nm length scale,” said professor Nealey. “We learned that by creating templates, we could drive those materials to form perfect patterns at that 3 to 50 nm length scale over arbitrarily large areas. That’s precisely the length scale needed for current and future integrated circuits.”

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Today’s cellular networks and data centers are built on a superhighway of ultra-high bandwidth optical fiber. But optical fiber suffers from a number of drawbacks, including challenging integration, deployment costs, and a very high rate of energy consumption. These drawbacks will limit its use in future networks.

Tomorrow’s global communication networks will be much denser and much more complex, and will provide far more bandwidth—so much more bandwidth that the design of communication systems will have to undergo a paradigm shift to meet the requirements. A key component of the new paradigm may be advanced CMOS technology, which supports very high data rates with relatively little energy consumption.

It was with this in mind that, in 2016, the RFIC lab at CEA-Leti began a partnership with Stanford University. The partnership was established with the goal of contributing to the design of a fully integrated CMOS transceiver that reaches 100 Gbps, with just $1$ petajoule per bit per meter of energy consumption.

To meet this goal, Leti and Stanford University set two major objectives. The first is to develop an innovative platform of aggressively scaled technologies for very low power, high-speed wireless communications. The idea is to develop tools for designing complex 3D electromagnetic passive structures—and to use these tools to design essential building blocks, such as oscillators, modulators and amplifiers. The second objective is to use these building blocks, along with other circuits previously designed by Stanford professor Amin Arbabian’s group, to develop a high-speed link.

As is often the case when two institutes collaborate, Stanford University and Leti naturally complemented one another when they set out to apply complex mathematical models to improve the design of photonic circuits. Stanford performed upstream research, providing innovative physical or mathematical concepts. Leti, at the crossroads of academic and industrial worlds, transformed those concepts into devices that can meet industrial needs and constraints.

“Among other things,” said Stanford professor Shanhui Fan, “Leti has a lot of state-of-the-art facilities for certification and testing of optical devices.”

Fan was well known for his leading research on numerical modeling of photonics devices. One noteworthy contribution was his work on optimization methods for designing highly efficient devices with non-intuitive shapes—configurations that can’t be designed by human engineers. While Leti has had a great deal of experience with silicon photonic devices, they had not yet mastered such complex mathematical optimization techniques.

The goal of the collaboration was to transfer the state-of-art techniques developed in Stanford to Leti, and then to develop efficient new models adapted to devices made of silicon and silica. This work should allow Leti to develop a new library of photonic components, much more compact and efficient than state-of-art, enabling enhanced silicon photonic circuits.

The partners succeeded in developing a new optimization method that is ideally suited to silicon photonics, taking into account the technological constraints of silicon photonics. Using this method, the partners designed new photonic devices to be fabricated and tested in Leti’s laboratories.

“Much of the work we did has the potential to impact a number of application areas,” said professor Fan. “I’m certainly looking forward to future collaborations with Leti.”

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“Leti’s extraordinary breadth and depth in communication and sensing areas make them unique partners for our center,” said professor Arbabian. “They have a strong presence in all layers of the system, and they bring expertise in semiconductor electronics, interfaces, signal processing, communication systems, and applications.”

“What stands out is their breadth and depth of knowledge and expertise; their ability to address challenges in many layers of the design hierarchy; and their scientific and fundamental approach to problem solving,” said Arbabian. “What’s more, researchers at Leti maintain close connections to industry needs as well as university innovations.”

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