leti
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TECHNOLOGY
RESEARCH
INSTITUTE

SCIENTIFIC REPORT
2016

SCIENTIFIC REPORT

2016

Since its foundation in 1967, Leti has shaped its strategy around the main challenges arising from the evolution of society and from global economic and industrial landscapes.

Increasingly engaged in European and global industrial ecosystems, Leti is leveraging basic science results to actively stimulate the creation of startups and foster innovation and value creation in large, small and medium businesses. In doing so, Leti greatly contributes to improve the competitiveness of its economic partners and create opportunities for growth and employment. This solidly anchored experience developing disruptive technologies and pioneering differentiating solutions means Leti is able to understand the applications and use cases of its partners and provide the technical building blocks that will meet their system-level requirements.

Leti's know-how and expertise is built on its scientific strategy which encourages true creativity and the discovery of new ideas and insights. Anticipating the arrival of new trends from many different origins, addressing issues that may arise during pre-industrial phases in a unique way, thinking large, seeing differently and demonstrating new solutions, this is our DNA.

"The best work is not what is most difficult for you; it is what you do best" said Jean-Paul Sartre, the French philosopher. What we do best is reported in these pages, often resulting from successful and long term collaborations with academic and industrial partners, whom we greatly acknowledge for their solid contributions. Finally, I would like to praise the remarkable skills, dedication and integrity of Leti's scientists: their outstanding commitment has been essential to creating these world-class successful results.

MARIE SEMERIA,
CEO - Leti

BARBARA DE SALVO,
CHIEF SCIENTIST, Leti

Before the discovery of Australia, people in the Old World assumed that all swans were white, an unassailable belief confirmed by empirical evidence. The sighting of the first black swan unsettled people's expectations, derived from millennia of well identified patterns believed to last forever. This single observation illustrates the ever expanding frontiers of human learning and knowledge.

At Leti, we praise incremental progress and we continuously challenge ourselves to look for the black swan in our research. Our strategy relies on highly creative investigation and recognition of non-conventional opportunities and innovative ideas. In this report, we would like to share some scientific highlights of our long-term exploratory research results, which have potential high technological and societal impact. These results will be presented along five strategic axes, aimed at capturing the complexity of today's world:

- Advanced materials: A driver of opportunities;
- How novel imaging techniques will revolutionize life, environmental and material sciences;
- Towards kinder and smarter medical approaches: New generations of stimulation, drug delivery technologies and monitoring systems;
- Energy efficiency at the device, chip, and board and system levels: ensuring the most efficient use of energy resources;
- Managing increasingly complex systems effectively and securely.

These results have been made possible thanks to the continuous efforts and authentic passion of our scientific experts and students. We also would like to acknowledge our academic partners for the many years of trustful and fruitful collaboration.

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LETI AT A GLANCE

- Founded in **1967**
- Based in **France** (Grenoble) with offices in the **USA** (Silicon Valley) and **Japan** (Tokyo)
- **350** industrial partners
- **1,900** researchers
- **2,700** patents in portfolio
- **91,500** sq. ft. cleanroom space, 8” & 12” wafers
- **60** startups created
- **€315** million annual budget
- **700** publications each year
- **ISO 9001** certified since 2000

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Leti is a technology research institute at CEA Tech and a recognized global leader in miniaturization technologies enabling smart, energy-efficient and secure systems. Our highly experienced teams are committed to developing innovative solutions that benefit our industrial partners.

By pioneering new technologies, Leti enables innovative solutions that ensure competitiveness in a wide range of markets, while creating jobs and improving people’s lives. Leti tackles critical, global challenges such as the future of industry, clean-and-safe energies, health and wellness, sustainable transport, information and communication technologies, space exploration and safety & security.

Leti’s multidisciplinary teams deliver solid expertise on micro- and nanotechnologies for applications ranging from sensors to data processing and computing solutions, leveraging world-class pre-industrialization facilities. Its pioneering technologies include low-power platforms for the IoT, low-cost multi-sensor solutions and 3D integration for cost-effective and low-power devices.

For 50 years, the institute has been building long-term relationships with its industrial partners – global companies, SMEs and startups – providing tailor-made solutions through bilateral projects, joint laboratories or collaborative research programs and a clear intellectual-property policy. Leti’s startup program actively supports the launching of new technology companies.

Over the years, Leti has collaborated with major research technology organizations and academic institutions to help bring upstream research to the marketplace.

Leti is a member of the Carnot Institutes network*.

**Carnot Institutes network: French network of 34 institutes serving innovation in industry.*

CEA Tech is the technology research branch of the French Alternative Energies and Atomic Energy Commission (CEA), a key player in research, development and innovation in defense & security, nuclear energy, technological research for industry and fundamental physical and life sciences.

In 2015, Thomson Reuters identified CEA as the most innovative research organization in the world.

www.cea.fr/english

HIGHLIGHTS

1. Challenging material choices to drive innovation

2. Seeing the world with novel imaging techniques

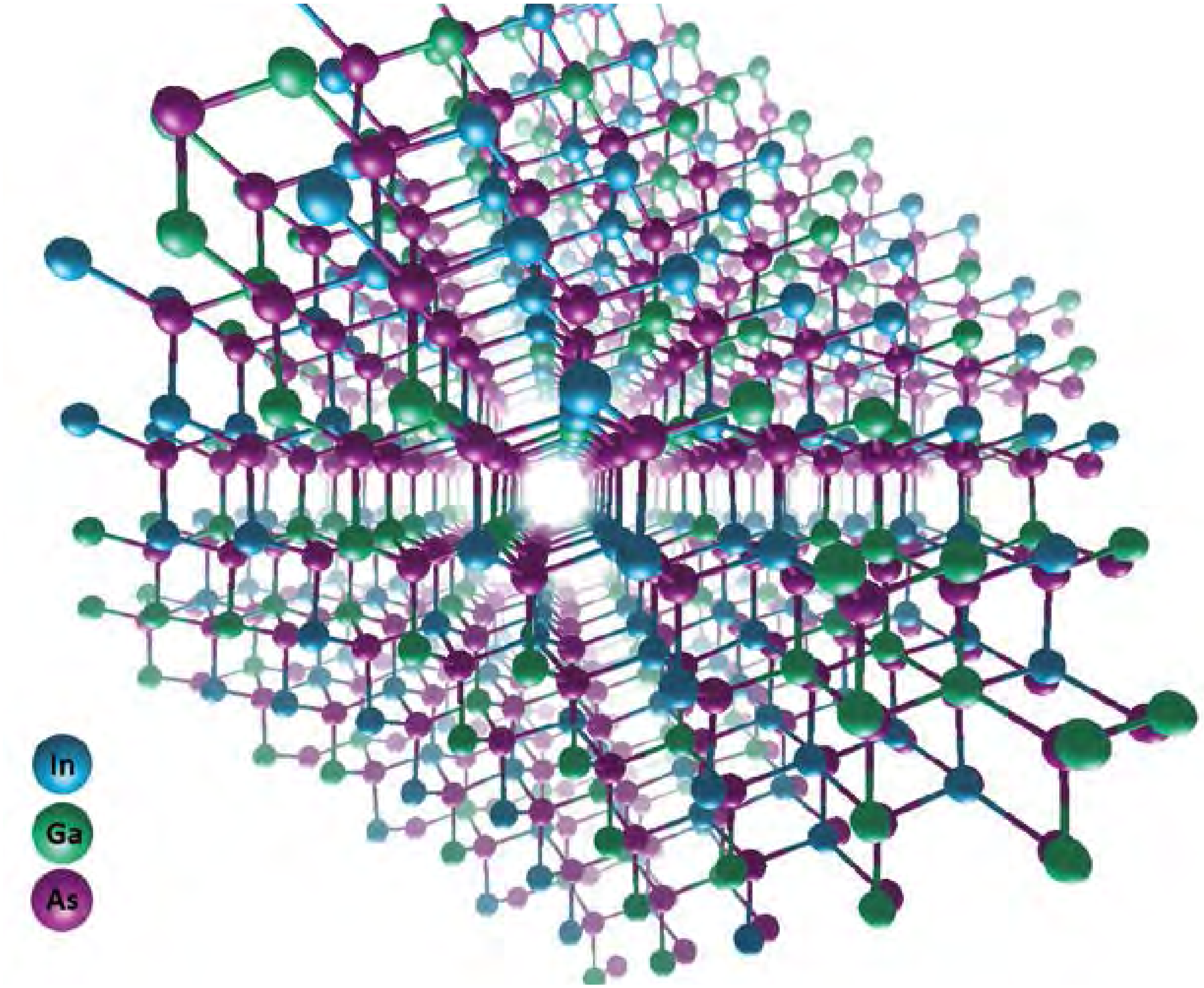
3. Technologies and smart systems to improve human health

4. Towards ultra-high energy efficiency at device and system level

5. Managing increasingly complex systems effectively and securely

1.

CHALLENGING MATERIAL CHOICES TO DRIVE INNOVATION



A MILESTONE IN A FUNDAMENTAL TRANSITION: FIRST 300 mm In GaAs-ON-INSULATOR WAFERS

JULIE WIDIEZ
Scientist

How did researchers at Leti harness SmartCut™ technology to accelerate the use of high-mobility III-V materials?

Today, the semiconductor industry stands on the verge of a historic transition away from silicon, its mainstay for almost 70 years. The high electron mobility and low electron effective mass values of III-V materials make them excellent candidates to become the new standard. But while several groups have produced InGaAs-on-insulator substrates by growing InGaAs layers on indium phosphide or silicon, these processes are complex and costly, and not always compatible with the industry standard 300 mm wafer diameter.

Our team took up the challenge by implementing a new MOCVD epitaxial deposition process and leveraging 20 years of experience with SmartCut silicon-on-insulator layer transfer and wafer bonding – and in 2015, created the world's first 300 mm InGaAs-on-insulator substrates, opening an avenue to effective and economical volume production.

We achieved this milestone by demonstrating the ability to grow high-quality 25nm-thick InGaAs layers directly on 300 mm silicon wafers, and successfully maintain their crystal quality while transferring them to wafers containing an insulating layer. At the same time, because SmartCut allows reuse of the expensive III-V donor wafer, the process has an intrinsic economic advantage.

What's the potential for integrating InGaAs into advanced manufacturing processes?

The next challenge, which we are working on, is the ability to transfer III-V layers onto processed CMOS wafers using proprietary CoolCube™ technology, which preserves solid thermal budgets for subsequent processing. This would allow a single substrate to have a bottom SiGe layer containing low-cost pMOSFETs and a high-mobility III-V top layer with high performance nMOSFETs.

Leti's ability to create this type of substrate would give designers and system developers a new paradigm for device scaling and dramatically increased CMOS power efficiency, along with the broader advantages of 3D integration (e.g. lower development costs, reduced circuit delay, less variation).

FIRST 300 MM INGAAS-OI WAFERS

BREAKTHROUGH:
Creating the first InGaAs-on-insulator wafers in the industry standard 300 mm size using SmartCut™ technology.

WHY IT'S RELEVANT:
Provides an alternative to silicon materials, whose fundamental physical limits are jeopardizing the chip industry's ability to maintain Moore's Law.

MOVING FORWARD:
Transfer III-V layers onto processed 300 mm CMOS wafers to enable heterogeneous 3D CoolCube™ architectures.

FOR MORE DETAILS

"First demonstration of 300 mm InGaAs-On-Insulator substrates fabricated using the Smart Cut™ technology"
J. Widiez, S. Sollier, T. Baron, M. Martin, G. Gaudin, F. Mazen, F. J. Widiez, S. Sollier, T. Baron, M. Martin, G. Gaudin, F. Mazen, F. Madeira, S. Favier, A. Salaun, S. Arnaud, S. David, E. Beche, H. Grampeix, C. Veytizou, D. Delprat, T. Signamarcheix / Proceedings of SSDM conference, 2015.

"300 mm InGaAsOI substrate fabrication using the Smart Cut™ technology"
S. Sollier, J. Widiez, G. Gaudin, F. Mazen, T. Baron, M. Martin, M. C. Roure, P. Besson, C. Morales, E. Beche, F. Fournel, S. Favier, A. Salaun, P. Gergaud, M. Cordeau, C. Veytizou, L. Ecarnot, D. Delprat, I. Radu, T. Signamarcheix / Proceeedings of S3S conference, p.1-2, 2015.

100X GAIN IN MICRODISPLAY BRIGHTNESS WITH GaN

FRANÇOIS TEMPLIER
Scientist

GAN MICRODISPLAYS

BREAKTHROUGH:
GaN technologies for lighting, together with high-resolution microdisplays.

WHY IT'S RELEVANT:
100x the brightness of existing emissive microdisplays. 10 µm pixel pitch is the smallest ever reported for hybridized GaN microdisplays.

MOVING FORWARD:
This result significantly changes the outlook for this technology, presenting applications ranging from augmented-reality systems to maskless lithography and wide-band optical communications.

Very tiny yet extremely bright. How did you reach these results in micro-LED technology?

Most currently available microdisplays have fundamental technology limitations that prevent the design of high-brightness, compact, very low-weight and low-power products.

To overcome this problem, we combined our research on gallium-nitride-based (GaN) technologies for lighting applications, together with high-resolution emissive microdisplays and high-resolution small-pitch hybridization technologies. Our results show a very small size of the micro-LEDs (6 µm) associated with extremely high-brightness – a groundbreaking change in this sector. In addition, the proposed technique is scalable and relies on a standard microelectronic large-scale fabrication process.

Our technology breakthrough features a brightness of more than 10^7 nits, which is several orders of magnitude higher than the ~10^3 nits obtained by state-of-art organic LED (OLED) microdisplays. We also demonstrated very high definition and the smallest pixel pitch for hybridized GaN microdisplays.

Other key innovations include micro-structuration of LED arrays (10 µm pitches or smaller) with high efficiency, and 3D heterogeneous integration (hybridization) of the LED arrays on CMOS circuits.

Where will Leti's micro-OLED expertise lead future research?

Leti has deep expertise on the full range of technologies to develop GaN microdisplays: from epitaxy, GaN array processing and hybridization to active-matrix design and display electronics.

Showing that high brightness can be achieved with such small pixel-pitch will first boost development of augmented reality systems and compact projectors. But these small-size, high-power LED arrays are also of great interest for other applications, such as maskless optical lithography and wide-band optical communications.

AWARD
Leti's GaN microdisplay won an "Innovation Award" at TechConnect World 2015 as one of the top 20 most-promising innovations.

FOR MORE DETAILS

"Blue and Green 10 µm pixel pitch GaN LED Arrays with very high brightness"
F. Templier, J-M. Bethoux, B. Aventurier, F. Marion, S. Tirano, M. Lacroix, M. Marra, V. Verney, L. Dupré, F. Olivier, F. Berger, W. Ben Naceur, A. Sanchot, I.-C. Robin, M.-A. di Forte-Poisson, P. Gamarra, C. Lacam, M. Tordjman, / Invited talk, the 22nd International Display Workshops 2015 (IDW'15), Otsu, Japan.

"Color conversion using red Quantum Dots integrated in a sol-gel on high-brightness blue GaN LEDs"
A. Sanchot, Fr. Templier, M. Consonni, St. Le Calvez, and I.-Chr. Robin / Proceedings of 2015 MRS Spring Meeting, April 6-10, 2015 San Francisco.

SUPERCRITICAL FLUID DEPOSITION FOR FABRICATING BIO-SENSING MEMS AND NEMS

GUILLAUME NONGLATON
Scientist

What is fundamentally eco-friendly about Leti's new SFD process?

This is the first reported example of deposition of an organic silane using a supercritical fluid-deposition tool (SFD-200) that is automated and compatible with 200 mm wafers. This "green" process was used to coat silicon wafers with oligonucleotides for bio-sensing applications and for coating of mesoporous silica with inorganic catalysts for heterogeneous catalysis applications.

We have shown that this versatile, environmentally friendly method enables conformal deposition of nonvolatile organic molecules on microdevices with complex geometries. We also demonstrated the feasibility of industrializing the process for MEMS or NEMS fabrication.

SUPERCRITICAL FLUID DEPOSITION (SFD)

BREAKTHROUGH:
Coating silicon wafers to graft oligonucleotides for bio-sensing applications and for coating organic catalysts on mesoporous silica for heterogeneous catalysis applications.

WHY IT'S RELEVANT:
The process enables new functionalities, and eliminates toxic solvents using standard CMOS processes.

MOVING FORWARD:
Leti will integrate this new technique in a fabrication process for the microelectronics industry starting from MEMS and NEMS and extending toward MOS applications.

How will this innovative chemical-deposition process change device fabrication?

Leti is developing SFD as a solvent-free methodology for chemical deposition, which for organic precursors is generally performed through liquid-phase methodologies. The problem is those processes involve large amounts of potentially toxic solvents and make it difficult to add innovative functions on microdevices or porous materials. SFD is the only methodology that can perform solvent-free chemical deposition for a large range of precursors.

The process offers many advantages over common methods in addition to eliminating solvents. It allows a controllable and thin silane layer, and a shorter time reaction. Moreover, it offers the possibility of simultaneously or consecutively depositing different organic precursors to build complex organic structures.

FOR MORE DETAILS

"Functionalization of silicon oxide using supercritical fluid deposition of 3, 4-epoxybutyltrimethoxysilane for the immobilization of amino-modified oligonucleotide"
J. Rull, G. Nonglaton, G. Costa, C. Fontelaye, C. Marchi-Delapierre, S. Ménage and G. Marchand / Applied Surface Science, vol. 354, Part B, pp. 285-297, 2015.

"Supercritical Fluid Deposition of epoxysilane on solid surface for biosensing and heterogeneous catalysis applications"
G. Nonglaton, G. Costa, C. Fontelaye, G. Marchand, C. Marchi-Delapierre, M. Ménage, J. Rull / EUROMAT 2015, Warsaw, Poland, 2015.

SILICON PHOTONICS: III-V-on-SOI TUNABLE LASERS

SÉGOLÈNE OLIVIER
Scientist

III-V-ON-SI TUNABLE LASER

BREAKTHROUGH:
A hybrid III-V-silicon-on-SOI laser was developed and packaged in an optical module with its electronic control card for wavelength allocation.

WHY IT'S RELEVANT:
Integration of these lasers on silicon paves the way for integration into more complex photonic ICs, such as transmitters and receivers for applications ranging from short-distance data communications to long-haul optical transmissions.

MOVING FORWARD:
Integration of the laser source is a very important step for reducing power consumption and scaling silicon photonics transmitter circuits to a larger number of wavelengths for next-generation optical transceivers.

What can you tell us about this innovation involving hybrid Si-photonics lasers?

In a joint project with French III-V Lab, we developed a tunable hybrid III-V-on-SOI laser and its packaging in an optical module with electronic wavelength allocation control. We achieved a wavelength tuning range of 35 nm, a side-mode suppression ratio (SMSR) higher than 50 dB, and an optical output power level coupled into a monomode fiber in excess of 3 mW across the whole wavelength range. The measured laser linewidth falls in the range of 500 kHz to 5 MHz over the entire wavelength range. Eighty wavelength channels separated by 50 GHz, as defined by the ITU grid for Dense Wavelength Division Multiplexing (DWDM) application, were allocated using an electronic control card.

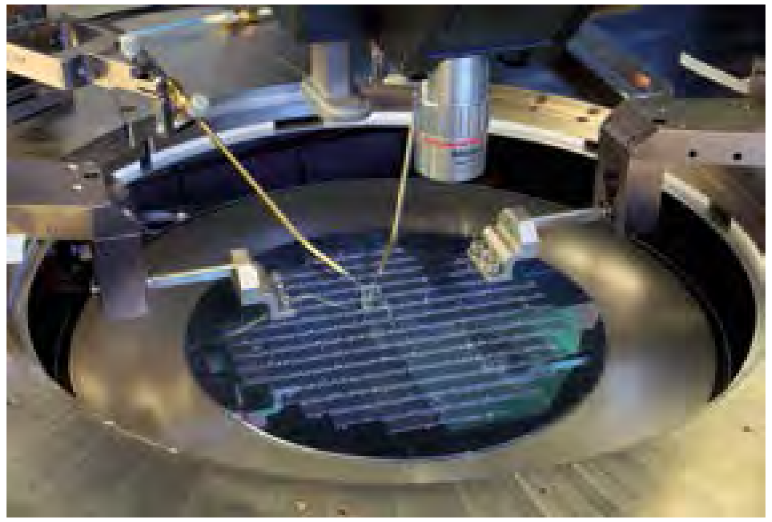
In the hybrid laser, the III-V material is used to provide large gain, whereas all the optical elements of the laser cavity are fabricated in silicon, leading to a compact and low-loss architecture.

The laser module demonstration was based on Leti's expertise in 200 mm wafer silicon photonics technology and molecular bonding.

How will this breakthrough impact future development and use of tunable silicon-photonics lasers?

The integration of these lasers on silicon paves the way for integration into more complex photonic ICs, such as transmitters and receivers for applications ranging from long-haul optical transmissions to short-distance data communications.

The competitive advantage is the integration of the laser source in the silicon photonics technology, which is key to cutting power consumption. In addition, the integration of the laser source is vital for scaling silicon photonics transmitter circuits to a larger number of wavelengths for next-generation optical transceivers in datacenters, or for future optical networks-on-chip. It greatly simplifies the packaging, which accounts for the major part of the transmitter cost.



FOR MORE DETAILS
"New Advances on Heterogeneous Integration of III-V on Silicon"
invited paper, G-H. Duan, A. Accard, P. Kaspar, C. Jany,, A. Le Liepvre, D. Make, G. Levaufre, N. Girard, A. Shen, J. Decobert, N. Legay, F. Lelarge, F. Mallecot, P. Charbonnier, H. Gariah, J.-L. Gentner, S. Olivier, S. Malhouitre, C. Kopp, and S. Menezo / Journal of Lightwave Technology, Vol. 33, 2015.

TOWARD LASERS MADE FROM DIRECT BANDGAP GERMANIUM-TIN ALLOYS GROWN ON SILICON

JEAN-MICHEL HARTMANN
Scientist

What combined contributions from FZJ and Leti led to this first-ever direct bandgap?

Monolithic integration of Si-based photonics and electronics is key for energy-efficient computing. Silicon-germanium-tin alloys, such as GeSn, SiGeSn or tensile-strained Ge are group-IV semiconductors of choice for this technology since band engineering allows the fabrication of direct bandgap materials. Not only passive optoelectronic components, but also light emitting devices like lasers and LEDs can strongly benefit from this intrinsic material property.

Leti's partner, Forschungszentrum Jülich (FZJ), demonstrated for the first time ever that a so-called direct bandgap, e.g. the energy difference between the top of the valence band and the bottom of the conduction, was achievable in group-IV semiconductors, using GeSn on Ge buffers from Leti. This major finding shows that having a direct bandgap means, among other things, that light or a laser, emitted by that semiconductor will be very intense compared to what can be obtained with regular silicon or germanium.

Leti provided 2.5 µm thick Ge buffers (on Si (001) substrates) for this research. Switching to Leti's state-of-the-art Ge buffers enabled FZJ to significantly improve the structural and electronic quality of their stacks and reach much higher Sn content – 12-13 percent vs. a previous maximum of approximately 8 percent – which is a prerequisite to obtaining a direct bandgap and a laser. "Direct" means that electrons, because of the peculiar band structure, will move from the conduction band down to the valence band without any phonon (e.g. lattice vibration) involved. That is far more efficient for light emission.

How will this breakthrough affect future R&D in direct-bandgap materials?

A group-IV laser could be monolithically integrated on top of CMOS devices and used as the light source of mid-infra-red photonics, with SiGe waveguides and GeSn photo-detectors as receivers. Clock frequencies could then be distributed within and in between chips, reducing energy use at big data centers, for example. These are valuable features for the Internet of Things and applications that support the green economy. They also could be light sources for gas detection in industrial and defense applications.

Applications for this technology also include toxic gas detection and quantification in industry and for defense purposes.

LASERS IN DIRECT BANDGAP

BREAKTHROUGH:
First-ever demonstration of a direct bandgap in group-IV semiconductors using GeSn on Ge buffers from Leti.

WHY IT'S RELEVANT:
It is a key step toward the fabrication of group-IV semiconductor lasers that could be monolithically integrated on Si substrates (although their threshold voltage is high compared to that in state-of-the-art III-V semiconductor lasers).

MOVING FORWARD:
Group-IV lasers integrated on CMOS devices could be used as light sources of mid-infra-red photonics. Clock frequencies could be distributed within and in-between chips, eliminating the need for metallic interconnects, accelerating device performance and minimizing power consumption.

FOR MORE DETAILS
"Lasing in direct-bandgap GeSn alloy grown on Si"
S. Wirths, R. Geiger, N. von den Driesch, G. Mussler, T. Stoica, S.Mantl, Z. Ikonic, M. Luysberg, S. Chiussi, J.-M. Hartmann, H. Sigg, J. Faist, D. Buca and D. Grützmacher / Nature Photonics 9, 88 (2015).

2.

SEEING THE WORLD WITH NOVEL IMAGING TECHNIQUES

THE EYES OF THE ELECTRONIC WORLD: PIXEL-LEVEL PACKAGING ADVANCES IR SENSORS

NICOLAS LIO SOON SHUN
Scientist

PIXEL-LEVEL PACKAGING OF IR SENSORS

BREAKTHROUGH:
Using a new infrared (IR) sensor manufacturing technique capable of creating separate isolating vacuums around millions of pixels.

WHY IT'S RELEVANT:
Replaces a cumbersome and costly wafer-level process; enables sensors with higher resolution, lower cost, less power consumption.

MOVING FORWARD:
Partner ULIS is bringing new generations of sensors to market using the Leti-developed technology.

How does Leti's technology in improved surface micromachining help computers see the world around them?

Among the millions of silicon wafers being processed annually, Leti's partner ULIS ran a special kind – one that first used a new infrared (IR) sensor manufacturing technique capable of creating separate isolating vacuums around thousands of individual pixels during front-end processing.

This pixel-level-packaging (PLP) approach, the product of six years of research at Leti, is a game-changing advance for microbolometer sensor cost and performance. Combining these better IR sensors with modern computing horsepower will enable systems to better interact with the environment around them, "seeing" objects even in the dark.

Our process creates a cavity under vacuum around each microbolometer pixel by stacking thin-film layers. It's a unique surface micromachining process, but uses standard microelectronic production techniques and equipment, and is ideal for high-volume production situations.

We created the first PLP image by projecting heat from a lamp through a handmade stencil, placed directly on a sensor that was still in its wafer. The image appeared immediately, much to our team's delight – and the stencil is now a precious lab keepsake.

How will this influence the linking of computer platforms and sensors?

The PLP approach eliminates the need to create vacuum packaging by sealing a separate cap wafer onto the component wafer. While this works well for MEMS devices like accelerometers, its cost, complexity and quality issues increase as sensor pixel size decreases – and smaller pixels are key to achieving higher resolution and/or lower cost and power consumption.

Improvements in infrared sensing will enable applications in which computing systems gather knowledge of their physical surroundings. In the near term, this has uses in energy efficiency, security, defense and industrial monitoring and control; going forward it will be essential for robotics and self-driving cars.

Because Leti's research has been structured from the outset for low cost and easy adoption into volume manufacturing, our partners are able to quickly leverage the advances and bring new generations of devices to market.

FOR MORE DETAILS
"Latest improvements in microbolometer thin film packaging: paving the way for low cost consumer applications"
J.-J. Yon, G. Dumont, V. Goudon, S. Becker, A. Arnaud, S. Cortial, C.-L. Tisse
/ Proceedings SPIE Vol. 9070 90701N, 2014.

REPLACING 19TH-CENTURY VOICE COIL MOTORS WITH PIEZOELECTRIC VARIFOCAL SMARTPHONE CAMERA LENSES

STÉPHANE FANGET
Scientist

How has Leti's MEMS expertise brought lens quality in smartphones to state of the art?

Smartphones are masterpieces of modern engineering. Yet, relatively few people know that one of their components is virtually unchanged since the 1870s: the voice coil motors (VCMs) used to focus smartphone camera lenses.

As scientists and engineers, we appreciate technology that endures, but the prospect of replacing these mechanisms with piezoelectric MEMS devices was very exciting because their greater precision enables true optical capabilities and the high-volume adoption of varifocal liquid lenses. Our innovative MEMS varifocal lens design, fabricated using standard production techniques, is a huge step forward, and because the camera function is one of the most-used smartphone capabilities, state-of-the-art lens technology is surely a key differentiator.

What design and production advances were needed for this breakthrough?

A 10-person team of piezoelectric materials experts, process-integration specialists, and MEMS designers used finite element modeling and extensive experimentation to design a deformable membrane-lens structure capable of encapsulating an optical oil, set in an embedded ring-shaped PZT piezoelectric actuator.

When a voltage is applied, the actuator displaces the oil and changes the shape of the lens, thus altering its focal length by up to 15 diopters. Just a few nanoamps of current are needed, so power consumption is several orders of magnitude less than VCM designs, while response time is an order of magnitude faster. This technique produces very good optical quality that endures over millions of cycles.

High-volume production compatibility was essential, so while we developed a proprietary fabrication process, our team focused only on industry-standard tools and techniques. It utilizes multiple polymer layers, including one that provides very good bonding between the silicon base wafer and top-level glass wafer, both 200 mm. We worked very hard to create a recipe that does not generate bubbles in the optical cavity after bonding, and were very excited that our partner, Wavelens, showcased a demonstration model at the 2015 Consumer Electronics Show in Las Vegas.

PIEZOELECTRIC VARIFOCAL SMARTPHONE CAMERA LENSES

BREAKTHROUGH:
Creating a new generation of smartphone optics with an innovative MEMS varifocal lens design, fabricated using standard production techniques.

WHY IT'S RELEVANT:
True optical autofocus capabilities are a powerful tool for smartphone users – and a market advantage for manufacturers.

MOVING FORWARD:
Our partner, Wavelens, is making the technology available commercially.

FOR MORE DETAILS
"Fabrication and Characterization of a New Varifocal Liquid Lens with Embedded PZT Actuators for High Optical Performances"
S. Nicolas, M. Allain, C. Bridoux, S. Fanget, S. Lesecq, M. Zarudniev, S. Bolis, A. Pouydebasque and F. Jacquet / 28th IEEE International Conference on Micro Electro Mechanical Systems (MEMS), Estoril, Portugal, 2015.

SETTING THE RECORD FOR INFRA-RED LIGHT CUTOFF LENGTH

NICOLAS BAIER
Scientist

INFRARED LIGHT DETECTION

BREAKTHROUGH:
The cutoff wavelength of IR light detectors was pushed to 17 microns.

WHY IT'S RELEVANT:
This leading development boosts performance in IR light space, defense and security applications.

MOVING FORWARD:
Increased knowledge of the material fosters ideas for innovative improvements and applications for Leti IR light detectors.

How does Leti's innovation in focal plain arrays change IR light-detection performance?

Our big breakthrough with Sofradir extended the cutoff wavelength of infrared light detectors past 15 µm, which was the project goal, to 17 µm, with a fully functional focal plane array. That has never been done before. Traditional detectors for security or defense applications on earth have cutoff wavelengths in the range 4-5 µm and 8.5-10 µm.

Leti's Infrared Lab is the only one in the world that demonstrates focal plane arrays (half-VGA format) with such cutoff wavelength and high functional pixel yield. The second part of the breakthrough is a major gain in dark current, two orders of magnitude higher than existing technology. And the third aspect is the optimization of the pixels' operability. This lowered the number of non-functional pixels (hard defects) and of pixels with temporal noise and/or with excess dark current.

Leti's experience in this technology began 30 years ago, and includes the creation in 1986 of Sofradir, now the world leader in developing and manufacturing infrared sensors for military, space and commercial security applications.

This innovation combined Leti's expertise in monocrystalline substrate growth, epitaxy of a high-quality active layer, specific technological processes, characterization of electro-optical performances and physic modeling.

What impact will this breakthrough have on future IR light detector R&D?

By increasing our knowledge of the material, new ideas emerged to propose new improvements or to open novel potential applications for our detectors. Some recent technological developments can be reused in other processes to increase performance, or to open access to brand new processes.

For our industrial partner, this provides ways to increase production yield and detector performance, thereby strengthening its position as a world leader in this domain.

FOR MORE DETAILS
"Latest Developments in Long-Wavelength and Very-Long-Wavelength Infrared Detection with p-on-n HgCdTe"
N. Baier, C. Cervera, O. Gravgrand, L. Mollard, C. Lobre, G. Destefanis, G. Bourgeois, J.-P. Zanatta, O. Boulade, V. Moreau
/ Journal of Electronic Materials, DOI: 10.1007/s11664-015-3851-0, 2015.

PRECESSION ELECTRON DIFFRACTION PROVIDES UNPRECEDENTED PERFORMANCE FOR STRAIN MAPPING AT NANOSCALE RESOLUTION

DAVID COOPER
Scientist

Pushing the envelope in transmission electron microscopy techniques. What are the implications for mapping strain?

As part of Leti's pursuit of innovative methods to improve the performance of SOI device technology, we are continuously developing new techniques that induce local strain in FDSOI processes for next-generation circuits. The introduction of strain is a very cost-effective way of improving performance, boosting speed and lowering power consumption.

It is highly desirable, when developing new device technologies, to provide maps of the strain during the different processing steps. That way, we can interpret the electrical properties and determine whether these improvements are due to the introduction of strain, or not.

Developed with Inac, this new technique uses precession electron diffraction in an aberration-corrected transmission electron microscope to achieve better than 2 nm spatial resolution and 0.02 percent precision for strain mapping of semiconductor specimens. We then map the deformation in the latest generation of devices, where feature sizes can be in the order of a few nanometers.

Leti is the only laboratory in the world that today has access to these methods of measuring deformation with this combination of spatial resolution and precision.

How will this breakthrough impact device manufacturing and what are the prospects for its further development?

We are working with the high-performance-microscope supplier FEI to make this a standard strain-mapping technique available to the semiconductor industry. FEI is supplying software specialists to improve the speed and efficiency of the data collection, in which a single map may contain several Gb of data.

We are also expanding on these ideas and have recently patented a method that can simultaneously measure electromagnetic fields, so that properties such as dopant potentials, piezo-electricity and magnetism can all be mapped at nm-scale resolution.

PRECESSION ELECTRON DIFFRACTION

BREAKTHROUGH:
A new transmission electron microscopy technique that provides unprecedented capabilities for mapping deformation in nanoscale devices.

WHY IT'S RELEVANT:
Strain is an important parameter in improving the performance of electronic devices. The ability to map strain with nm-scale resolution will allow the different processing steps to be optimized to provide the best performance.

MOVING FORWARD:
We continue to develop new characterization methods that can be used to support nanotechnology activities. One current direction is studying these devices at atomic resolution, while they are being operated in-situ in the electron microscope.

FOR MORE DETAILS
"Combining 2-nm Spatial Resolution and 0.02% Precision for Deformation Mapping of Semiconductor Specimens in a Transmission Electron Microscope by Precession Electron Diffraction" D. Cooper, N. Bernier and J.-L. Rouvière
/ Nano Letters, pp. 5289–5294, July 28, 2015.

MILLIMETER-WAVE RFICS

ALEXANDRE SILIGARIS
Scientist

MILLIMETER-WAVE RFICS

BREAKTHROUGH:
The first demonstration of higher-quality image using locked oscillator in heterodyne imaging system.

WHY IT'S RELEVANT:
Opens the THz spectrum for imaging, and allows new research possibilities in medical imaging, biology, material control, security and other fields.

MOVING FORWARD:
Building a demonstrator that makes THz images without lab equipment, and designing new circuits to increase performance and integrate more functionality.

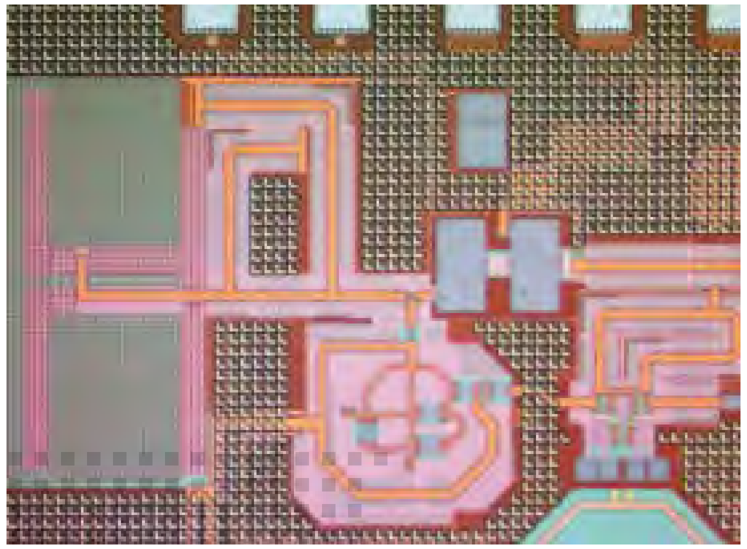
How will Leti's achievement in millimeter wave 300 GHz RFICs raise the bar for imaging?

Leti's RFIC circuit that operates near 300 GHz in a standard technology offers very good sensitivity and vectorial detection – double information on the scanned object – integrated in a single chip. The essential differentiator in Leti's approach is that our receiver, or detector for imaging purposes, uses a heterodyne architecture with integrated oscillator. Moreover, the oscillator is locked by a stable signal at lower frequencies. Thus, the frequency synthesis is not carried out at 300 GHz, which is above the 200 GHz cut-off limit for transistors, but at much lower frequency, with higher performance. This approach greatly enhances image contrast.

Leti is the first to demonstrate that better image quality can be achieved if the oscillator is locked in a heterodyne imaging system.

What new research possibilities will THz spectrum imaging open?

As we approach the 300 GHz frequency, for which the wavelength is about 1 mm in free space, we can imagine detectors, likely radars, which scan an object with 1 mm or less spatial resolution. With that capability, we can construct an image with good resolution in a frequency spectrum not yet available for these uses. Imaging exists today in the visible spectrum, the X-ray spectrum, the infrared spectrum and also in the RF spectrum, but not in the so-called THz spectrum. This spectrum can reveal new elements in biological materials since it behaves as a radio-frequency wave and has very interesting spatial resolution. Our work opens the THz spectrum for imaging, allowing new research in medical imaging, biology, material control, security and other fields.



FOR MORE DETAILS
"A 270-to-300 GHz Sub-Harmonic Injection Locked Oscillator for Frequency Synthesis in Sub-mmW Systems"
A. Siligaris, Y. Andee, C. Jany, V. Puyal, J. M. Guerra, J. L. G. Jimenez and P. Vincent
/ IEEE Microwave and Wireless Components Letters, vol. 25, no. 4, pp. 259-261, 2015.

"A 278 GHz heterodyne receiver with on-chip antenna for THz imaging in 65 nm CMOS process"
A. Siligaris, Y. Andee, E. Mercier, J.-M. Guerra, J.-F. Lampin, G. Ducournau and Y. Quere
/ IEEE European Solid-State Circuits Conference (ESSCIRC), Graz, pp. 307-310, 2015.

NON-DISPERSIVE INFRARED (NDIR) TECHNOLOGY

PIERRE BARRITAULT
Scientist

How will Leti's breakthroughs in NDIR technology impact air-monitoring equipment?

In the first of three major innovations, we took state-of-the-art blackbody IR source technology to a new level by using a wafer-level-packaging (WLP) source, fabricated on 200 mm wafers in CMOS processes. We capped each source under vacuum by positioning a second wafer above the wafer-source and sealing both wafers under vacuum (WLP). That eliminated the air surrounding the source and the thermal losses. As a result, the electrical-to-optical conversion efficiency is multiplied by 20.

The optical design, the second breakthrough, allows us to image the source on the IR detector within a compact optical cavity, while maintaining very high efficiency.

The third major innovation was the development of an IR pyro-electric detector to replace the standard detector used in our prototypes. The advantage is clearly to master the design and manufacturing of all the components used in the NDIR detector – source, optical cavity and detector – thus enabling an optimized design.

How will the Leti startup, eLichens, put these innovations to work?

eLichens' technology, which detects, monitors and predicts air quality indoors and outdoors, is based on a portfolio of 20 Leti patents that reduce existing large and expensive sensors used in industrial applications to a size that fits in hand-held devices. These innovations will enable eLichens to improve performance and reduce power consumption with its products.

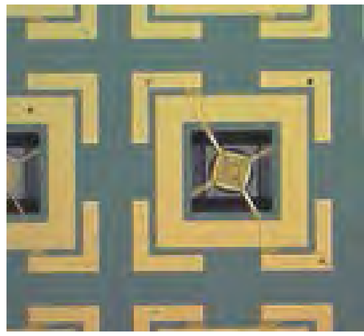
eLichens and Leti plan to develop CO_2 NDIR sensors with an ultra-low power consumption (a few mW) and a compact size (25x25x7 mm). CO_2 will be the first targeted gas, with others to follow.

NON-DISPERSIVE INFRARED TECHNOLOGY

BREAKTHROUGH:
Low-power use, high performance through WLP; optical design allows imaging in compact optical cavity and new circuits to improve performance.

WHY IT'S RELEVANT:
The main differentiator of our sensors is ultra-low power consumption – in the order of a few mW.

MOVING FORWARD:
The goal is to industrialize the production of the source, the optical cavity and the CO_2 sensor.



FOR MORE DETAILS
"Mid-IR source based on a free-standing microhotplate for autonomous CO_2 sensing in indoor applications"
P. Barritault, M. Brun, S. Gidon, S. Nicoletti / Sensors and Actuators A: Physical, vol. 172, no 2, pp. 379-385, 2011.

"Low power CO_2 NDIR sensing using a micro-bolometer detector and a micro-hotplate IR-source"
P. Barritault, M. Brun, O. Lartigue, J. Willemin, J.-L. Ouvrier-Buffet, S. Pocas, S. Nicoletti
/ Sensors and Actuators B: Chemical, vol. 182, pp. 565-570, 2013.

3.

TECHNOLOGIES AND SMART SYSTEMS TO IMPROVE HUMAN HEALTH

WIRELESS BRAIN-COMPUTER INTERFACE OFFERS MOBILITY TO TETRAPLEGIC PATIENTS

CORINNE MESTAIS
AND GUILLAUME CHARVET
Scientists

BRAIN-COMPUTER INTERFACE (BCI) FOR TETRAPLEGIC SUBJECTS

BREAKTHROUGH:
A full BCI system for long-term human use outside the lab, including a wireless 64 ECoG recording implant WIMAGINE®.

WHY IT'S RELEVANT:
This BCI system is the only wireless system developed for chronic human use outside the lab.

MOVING FORWARD:
Additional applications include BCI systems for other severe motor disabilities and brain monitoring activities, including for epilepsy.

The full BCI system for long-term use is nowhere else available. How did Leti Clinatec achieve this milestone?

The objective of the brain-computer interface project at Clinatec is to demonstrate that tetraplegic patients will be able to learn to control complex effectors, such as a 4-limb exoskeleton, through brain-activity monitoring and decoding. Delivery of the world's only full-BCI system for extended human use is the highlight of the project. Unlike invasive BCI systems that have been tested in clinical trials, ours is the only wireless one and it was developed for chronic use outside the lab.

This multidisciplinary project required the development of a 64-channel electrocorticography (ECoG) recording implant called WIMAGINE® for long-term use, innovative signal processing algorithms and a 4-limb exoskeleton developed by List, Leti's fellow CEA Tech institute.

WIMAGINE records on 64 electrodes with selectable gain and sampling frequency, with less than 0.7 µVRMS input referred noise in the [0.5 Hz - 300 Hz] band. It is powered remotely through an inductive link at 13.56 MHz, and communicates wirelessly on the MICS band at 402-405 MHz with a custom designed base station connected to a PC. It also complies with the regulations applicable to class III AIMD (Active Implantable Medical Devices). The design of the housing and the antenna has been optimized to ease the surgery and to take into account all the requirements of a clinical trial, in particular patient safety and comfort.

In addition to satisfying all regulatory constraints, the full BCI system was approved by French authorities (ANSM and the Ethics Committee) for the clinical research protocol "BCI and tetraplegia".

While leveraging Leti's expertise in medical-device architecture that addresses miniaturization, ultra-low power, safety and reliability, the project also made great use of the Clinatec platform that integrates state-of-the-art facilities for medical-device design and manufacturing. This includes expertise in electronics, packaging, signal processing, software and robotics.

How will this breakthrough influence future R&D on BCIs for medical applications?

While the principal application is restoring functional movement for individuals with severe motor impairment, the system bricks (such as the WIMAGINE® implants) can be used for other brain monitoring activities, including for epilepsy.

Clinatec also provides a powerful model of the advantages of multidisciplinary teams located in the single facility, where they can complete complex medical-device development projects along the whole development cycle: from system to first clinical evaluations.

FOR MORE DETAILS
"WIMAGINE®: Wireless 64-channel ECoG recording implant for long term clinical applications"
C. Mestais, G. Charvet, F. Sauter-Starace, M. Foerster, D. Ratel & A.-L. Benabid / IEEE Transactions on Neural Systems and Rehabilitation Engineering, Volume: 23, Issue: 1, DOI: 10.1109/TNSRE.2014.2333541 2015.

OXIMETRY SENSOR: A WIRELESS CONFORMABLE PATCH FOR TREATING SLEEP APNEA

ANNE KOENIG
Scientist

WIRELESS OXIMETRY SENSORS

BREAKTHROUGH:
A wireless device uses reflectance to monitor oxygen saturation in the blood, eliminating the need for invasive devices wired to patients.

WHY IT'S RELEVANT:
A wireless, conformable patch and its mobile application for physical activity and spO_2 measurement associated with digital biomarkers. This provides clinicians with a reliable computer-aided diagnostic tool for non-invasive rapid and continuous monitoring of sleep respiratory disorders.

MOVING FORWARD:
Extending its application to diagnose additional medical conditions, as future R&D addresses the complete development of the patch with other types of sensors.

How does Leti's novel technology for measuring oxygen saturation in the blood enhance existing techniques?

Combining expertise in wearable actimetry sensors and oximetry, Leti developed a less invasive and more reliable device to diagnose Obstructive Sleep Apnea (OSA) in patients affected by respiratory problems. This innovation is the result of a joint effort of Leti and its medical-industry partner to address a widespread pathology in adults.

The standard method of measuring oximetry is based on transmittance mode requiring small clamps attached to a finger and wired to a recorder. Integrating skin optical sensors and the Blue Tooth low-power protocol, Leti's spO_2 wearable sensors monitor oxygen saturation in the blood in a reflectance mode on different locations on the body, such as the forehead and wrist, thereby eliminating the need for devices wired to patients.

Usual polysomnography methods require a lot of sensors that cause abnormal sleep conditions, and therefore biased data, whereas Leti's approach provides a compact, wireless and user-friendly solution.

This innovation resulted from our team's combined expertise in optics, instrumentation, low-power electronics, simulation of light diffusion in the skin and embedded systems.

What research opportunities does this conformable patch breakthrough suggest for further medical benefits?

Obstructive sleep apnea (OSA) syndrome is an under-diagnosed pathology affecting up to 7 percent of adults, so there is a large group of potential beneficiaries.

Digital markers already identify for obstructive apnea and provide continuous monitoring and longitudinal analysis. Using this sensor will allow automated detection of several types of apneas and other respiratory problems.

Future R&D will address the complete development of the patch with other sensors, such as a PCO_2 sensor (partial pressure of CO_2 in the blood).

FOR MORE DETAILS
"A wireless patch for sleep respiratory disorders applications"
R. Gerbelot, A. Koenig, C. Goyer, J. Willemin, C. Désir, J. Porcherot, H.-S. Kane, R. Guillemaud, J-C. Borel, & P. Jallon / EMBS Milan, 2015.

FIGHTING BIO-TERRORISM WITH TECHNOLOGY: A MOBILE RICIN DETECTION SYSTEM

DOROTHÉE JARY
Scientist

MOBILE RICIN DETECTION SYSTEM

BREAKTHROUGH:
Integrating Leti's microfluidic genetic analysis experience with knowledge from diverse fields to create an automated diagnostic system for ricin exposure.

WHY IT'S RELEVANT:
Toxicogenomic technology allows immediate on-site assessment of personal exposure to ricin during possible bio-attacks.

MOVING FORWARD:
Apply the mRNA/RT-qPCR analytical principles and system design to other point-of-care diagnostics, possibly through a Leti startup.

What was the most challenging aspect of creating a mobile automated device to quickly evaluate exposure to the bio-toxin ricin?

When we accepted the challenge of producing a portable ricin detection system, our team knew it would require insight from many disciplines. Leti's background in on-chip microfluidics for EWOD genetic analysis, particularly of individual cells, was essential to achieve rapid automatic detection. Our team was able to perform this in less than 90 minutes under field conditions. However, developing an integrated system also required a multidisciplinary expertise in biology, chemistry, material science, industrial design and instrumentation.

Using a PMMA material for the chip, rather than the PDMS traditionally used for toxicogenomics, provided a more robust device, suitable for point-of-care use, which could be easily produced in volume. Our interdisciplinary team designed an associated cartridge to hold reagents and control the process, including extraction of genetic material from a 10µl blood sample and management of multiple parallel tests of RT-qPCR reactions. We also developed new competencies in high-resolution machining of plastics, proprietary on-board micro-valve technologies and novel biological protocols.

The biggest advance in 2015 was on a task that sounds simple, and yet proved to be exceptionally difficult: evenly filling the bio-chip's network of 28 micro-chambers with a precise mixture of the test subject's mRNA and analytical materials. After struggles with uneven filling and bubbles created during heating steps, our team hit upon an audacious solution: using a short burst of relatively high pressure (up to 1 bar) to inject the mixture in less than one second. It was a great day when we achieved flawless filling and analysis!

How will this type of tool affect the health care field beyond first response to possible bio-weapon attacks?

By integrating a microfluidic system with innovative host-response analysis, our team has opened a wide range of biological analysis opportunities. One primary target is early point-of-care diagnosis of infectious diseases in biological fluids, through rapid and sensitive detection of molecular biomarkers. There are also a number of identified markets in the veterinary field, and in environmental monitoring applications such as food and water quality. Development is continuing, and our team is evaluating the creation of a startup company to commercialize these research achievements.

FOR MORE DETAILS
"Point-of-care diagnostics for ricin exposure"
M. Lemine, Y. Diakite, J. Rollin, D. Jary et al,
/ Lab on a Chip, vol. 15, no. 10, pp. 2308-2317, 2015.

GIVING MEDICINE A CLOSER LOOK WITH SPECTROMETRIC IMAGE DETECTORS

MARC ARQUES AND JEAN-LUC MORO
Scientists

What will this innovation in dual-energy detectors mean for 2D X-ray imaging?

The energy of X-rays that are detected after going through an object depends on the composition of the object. Existing X-ray technology based on integrating detectors measures the mean X-ray absorption of the irradiated objects without distinguishing the photons' energy. Our early-stage, innovative detector delivers a measure of the energy of the X-rays it detects, i.e. it performs spectrometry.

For medical applications, comparing absorption levels at low and high energies distinguishes bones from soft tissues, as well as contrast media such as iodine or gadolinium.

The innovation we are working on also changes the format of detectors. Most present spectrometric or multi-energy detectors are either linear detectors or small 2D detectors typically measuring 1 to 4 cm². These detectors generally use a photoconducting semiconductor X-ray absorber such as cadmium telluride (CdTe) coupled to a small silicon readout circuit.

Combining Leti's expertise in global detector design, readout circuit design and characterization, image signal processing and other fields, we are working on a new solution compatible with large 2D detectors, e.g. 10x10 to 20x20 cm². For this, we are using a low-cost scintillator absorber, which detects X-rays or gamma rays and, at this time, a small 2D silicon readout circuit.

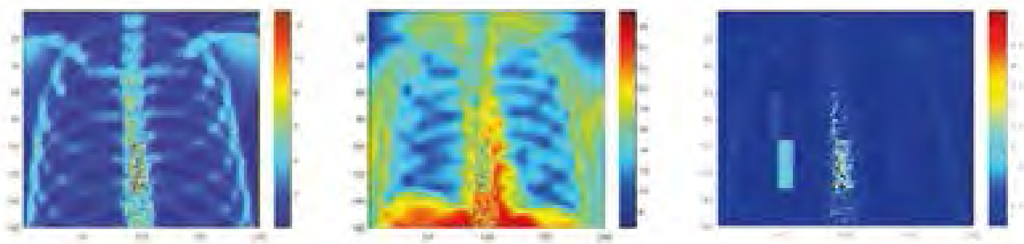
While the scintillator is cheaper than photoconductors, it is less sensitive, so our focus is on a detector with very low readout noise, e.g. 100 electrons. Because the detector will have a large 2D pixels matrix, we must make sure each pixel consumes very little power: less than 5 µW.

SPECTROMETRIC X-RAY DETECTORS

BREAKTHROUGH:
Measuring energy differences of X-ray photons on large 2D detectors.

WHY IT'S RELEVANT:
Improves cancer diagnostics by allowing radiography technicians to distinguish between tissue and bones.

MOVING FORWARD:
Besides continuing work on scaling up the devices, our challenges include automatic pixel binning to summarize the pixels' information when a photon is detected between two pixels and shares its information between them.



How will this breakthrough impact medical radiography?

If everything goes as planned, we will be able to develop a new solution compatible with large 2D detectors, which will significantly improve medical imaging.

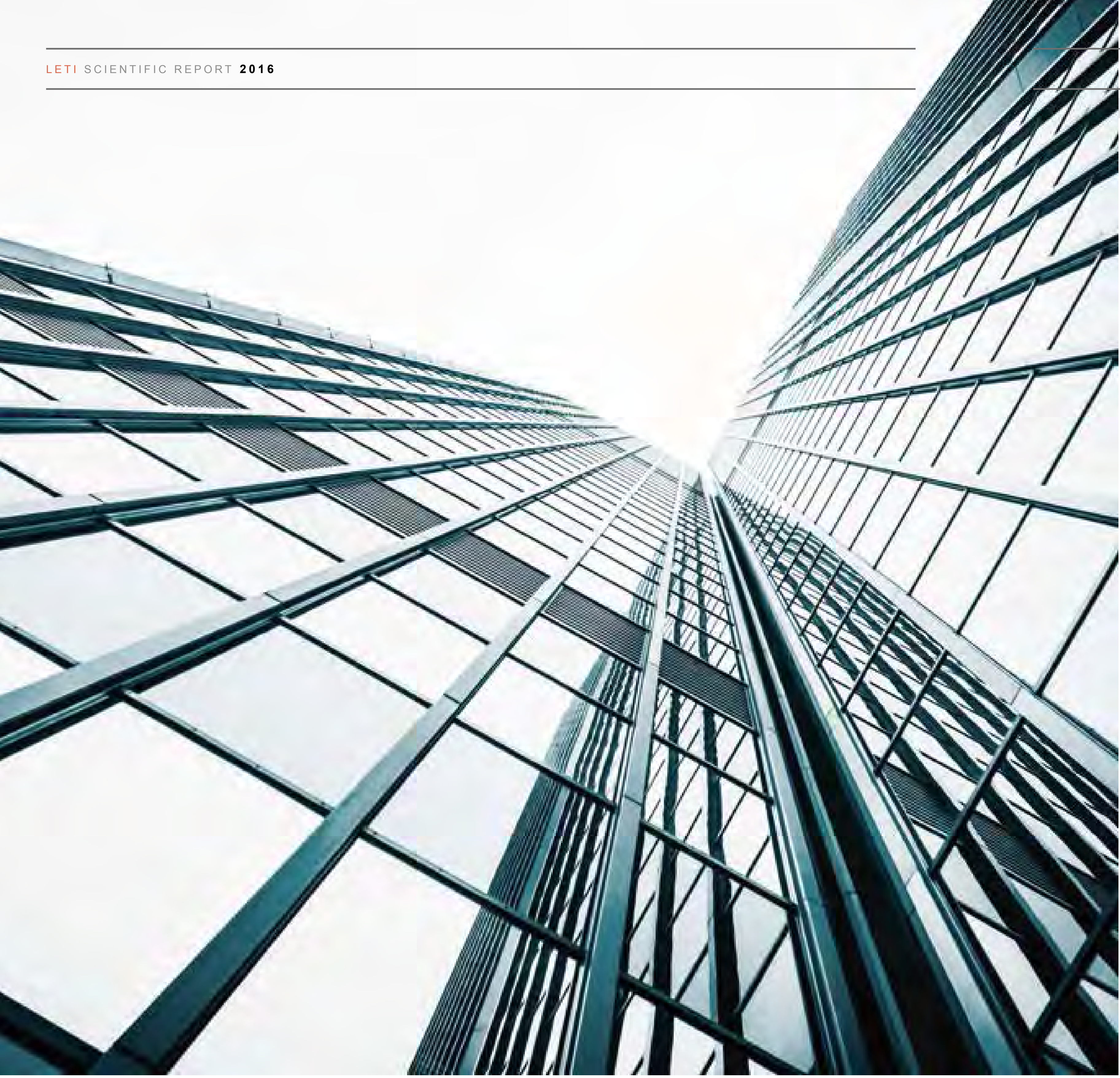
For example, in traditional radiography, lung cancer nodules appear as bright spots that overlap on the ribs. This overlapping interferes with the detection of the nodules. By recognizing the X-ray energy, we see the patient's ribs, and we can remove them from the image. This provides a much better picture of the cancer nodules.

The technology could also be used outside of the medical field, e.g. for security or non-destructive testing applications.

FOR MORE DETAILS
"Sphinx1: Spectrometric Photon Counting and Integration Pixel for X-ray Imaging with a 100 electron LSB"
A. Habib, M. Arques, B. Dupont, P. Rohr, G. Sicard, M. Tchagaspanian and L. Verger
/ IEEE Transactions on Nuclear Science, Volume 62, Issue 3, 2015.

4.

TOWARDS ULTRA-HIGH ENERGY EFFICIENCY AT DEVICE AND SYSTEM LEVEL



COOLCUBE™, A LOW-TEMPERATURE ROUTE TO FURTHER 3D VLSI SCALING

OLIVIER FAYNOT
Scientist

How was Leti able to achieve first electrical results with CoolCube™ on 300 mm wafers?

As a reminder, 3D VLSI with a CoolCube™ integration allows vertically stacking several layers of devices with a unique connecting-via density above a million/mm². To benefit from this via density and get improved IC performance, the top layer needs to be fabricated without impacting the electrical characteristics of the bottom one. As a consequence in order to achieve electrical results with CoolCube™, Leti had first to set up a fabrication flow for CMOS devices where the whole thermal budget was kept in the 600°C range.

We specifically focused on epitaxy, spacers, gate stack and junction annealing, harnessing the mainstream trend where process temperature tends to decrease. For dopant activation we relied on Solid Phase Epitaxy Regrowth to decrease the activation temperature from 1050°C down to 500°C. To achieve the 300mm demonstration we also had to elaborate a contamination containment strategy in order to guaranty Front-End-Of-Line wafer quality even after bonding for the top layer process.

How will this thermal budget breakthrough influence future CoolCube™ R&D?

This breakthrough validates the feasibility of CoolCube™ technology. We enter now in a new phase where we can focus on optimization of the performance and demonstrators fabrication. We can target applications and customize the top layers for their dedicated needs. As an example, CoolCube™ can be used to provide optimized CMOS partitioning where I/Os transistors are in the top layer whereas the digital part lays in the bottom one.

COOLCUBE™ AND 3D VLSI SCALING

BREAKTHROUGH:
A low-temperature fabrication flow for CMOS devices in 300mm.

WHY IT'S RELEVANT:
The 3D CoolCube™ technology allows vertically stacking several layers of devices with a unique connecting-via density above a million/mm² offering lower-cost manufacturing processes and high-performance applications.

MOVING FORWARD:
Focusing on CoolCube™ applications, as demonstrators with optimized CMOS partitioning where I/Os transistors are in the top layer and the digital part in the bottom one.

FOR MORE DETAILS

"3D VLSI-CoolCube Process: An Alternative Path to Scaling"
P. Batude, C. Fenouillet-Beranger, L. Pasini, V. Lu, F. Deprat, M. Cassé, B. Mathieu, B. Sklenard, F. Piegas-Luce, O. Billoint, O. Turkyilmaz, H. Sarhan, S. Sollier, J. Widiez, C. Tabone, M.-P. Samson, B. Previtali , N. Rambal, F. Ponthenier, J. Mazurier, R. Beneyton, M. Bidaud, E. Josse, E. Petitprez, O. Rozeau, S. Martini, L. Brunet, M. Rivoire, C. Euvard-Colnat, A. Seignard, F. Fournel, L. Benaissa, J.-M. Hartmann, P. Besson, S. Kerdiles, C. Bout, F. Nemouchi, A. Royer, G. Ghibaudo, T. Signamarcheix, M. Haond, F. Clermidy, O. Faynot and M. Vinet / VLSI Technology Symposium, 2015.

"High Performance CMOS FDSOI Devices activated at Low Temperature"
L. Pasini, P. Batude, J. Lacord, M. Casse, B. Mathieu, B. Sklenard, F. Piegas Luce, J. Micout,, A. Payet, F. Mazen, P. Besson, E. Ghegin, J. Borrel,, R. Daubriac, L. Hutin, D. Blachier, D. Barge, S. Chhun, V. Mazzocchi, A. Cros, J-P. Barnes, Z. Saghi, V. Delaye, N. Rambal, V. Lapras, J. Mazurier, O.Weber, F. Andrieu, L. Brunet, C. Fenouillet-Beranger, Q. Rafhay, G. Ghibaudo, F. Cristiano, M. Haond, F. Boeuf and M. Vinet / VLSI Technology Symposium, 2016.

DEMONSTRATING SILICON'S SUITABILITY FOR QUANTUM COMPUTING

MAUD VINET
Scientist

DESIGNING QUANTUM BITS

BREAKTHROUGH:
The first demonstration of a qubit device on a Si CMOS platform.

WHY IT'S RELEVANT:
A significant step towards implementing a quantum computer based on silicon.

MOVING FORWARD:
Addressing the many challenges to scaling. Adapting industrial SOI's established processing and integration techniques will move qubits closer to realization.

How were Leti and INAC able to demonstrate a quantum bit in SOI?

This world's first demonstration of a qubit device on a foundry-compatible Si CMOS platform adapted SOI nanowire MOSFET technology to essentially fabricate a compact two-gate pFET. The qubit was encoded in the spin degree of freedom of a hole quantum dot defined under one of the gates. In order to demonstrate spin-state control, the classic analogy of bit initialization or performing operations on a bit, we applied a RF electric field directly to the gate itself.

These results stem from more than a decade of research on using FDSOI silicon nanowire technologies to design devices with an accurate control of single charge. In 2015, we also demonstrated the design of quantum dots with diameters as small as 3.4 nm, and gate length in the 10 nm range. We very reliably controlled the charge state at room temperature, because of the large charging energy of the ultra-scaled quantum dots.

Quantum computing is widely regarded as representing a major new IT frontier. What will future R&D focus on?

Elementary silicon qubit devices made in academic research labs have already shown high-fidelity operation. In addition, transferring control and readout methods from GaAs spin qubits to Si-based structures has shown outstanding qubit performance in prototypical SiGe, Si and 28Si MOS qubits. But many challenges remain before industry will see a prototype computer. These include slow manipulation rates, low-fidelity two-qubit gate operations and, more generally, problems such as valley degeneracy, charge noise, nano-lithography control and device variability. These present a major hurdle for scaling.

We will continue our approach of leveraging the well-established device-processing and integration capabilities of industrial SOI technology. This offers industry-standard reliability and reproducibility, along with low-noise characteristics and low variation in device parameters – essential advantages for overcoming the main challenges.

FOR MORE DETAILS

"Quantum Dot Made in Metal Oxide Silicon-Nanowire Field Effect Transistor Working at Room Temperature"
R. Lavieville, Fr. Triozon, S. Barraud, A. Corna, X. Jehl, M. Sanquer, J. Li, A. Abisset, I. Duchemin, and Y.-M. Niquet
/ Nano Letters, pp. 2958–2964, 15 (5), 2015.

"Si CMOS Platform for Quantum Information Processing"
L. Hutin, R. Maurand, D. Kotekar-Patil, A. Corna, H. Bohuslavskyi, X. Jehl, S. Barraud, S. De Franceschi, M. Sanquer, M. Vinet
/ IEEE VLSI Technology Symposium, Hawaii, USA, 2016.

MAINTAINING MOORE'S LAW WHEN LOW-POWER NANO DEVICES ARE PUSHED TO THEIR LIMITS

VALENTIN SAVIN
Scientist

Your i-RISC project proposed a unique approach to designing fault-tolerant nanoscale logic circuits with unreliable components. What can you tell us about that?

Nanoscale integration of reliable chips built with error-prone hardware is one of the most critical challenges for next-generation electronic circuit design. Our team in this EC FET Open project understood that fault-tolerant error correction could support innovative solutions for designing reliable systems even with unreliable components.

We also realized that this challenge called for a plan of attack that combined disciplines and techniques from many sources. We were the first team to pursue fault tolerance by combining techniques from coding theory, graph-based multi-objective optimization and logic synthesis. We also leveraged ideas and techniques from a variety of research areas, such as communications and circuit/system theory. The design approaches were also unique. For example, our team built effective error-correcting codes tailored to nano-era fault density and probability, and codec architectures that provided reliable error protection even with faulty hardware. We also developed a design method that combines the codec architecture with the hardware it protects, and optimized the design for energy consumption, latency and reliability.

The project even served up a few surprises. While prevailing opinion holds that unreliable hardware is harmful, in some cases randomness from hardware noise actually improved the error-correction performance of some of the investigated decoders.

Our results paved the way toward reliable synthesis of logic circuits from unreliable components, as well as reliable storage and transfer of digital information throughout the chip.

How will these novel fault-tolerant design solutions influence future nanoelectronic circuit design?

The implications are both manifold and exciting. Reliable nanoscale integration of chips built with faulty hardware could lead to completely new solutions for next-generation, low-power electronic circuit design. This is especially important because the physical properties of nano devices are being pushed to their limits.
The proposed fault-tolerance solutions may be particularly relevant to the design of low-power integrated circuits in the presence of deep submicron noise.

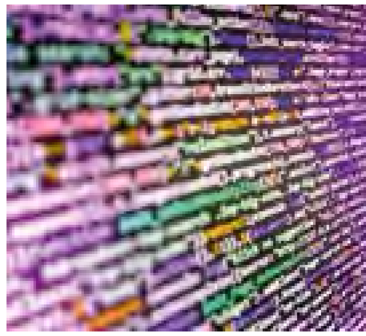
More generally, applying modern coding theory to the development of novel fault-tolerant devices provides a new measure of performance in memory and computing systems. In the future, the proposed techniques may be used in post-CMOS technologies, and the project opens a promising path to maintaining Moore's Law.

FAULT TOLERANCE IN LOGIC CIRCUITS

BREAKTHROUGH:
A novel combination of disciplines and techniques for designing reliable error-protected circuits even with faulty hardware, while optimizing energy consumption and latency.

WHY IT'S RELEVANT:
These fault-tolerant design techniques offer a promising path to maintaining Moore's Law in the nanoelectronics era, when physical properties of nano devices are being pushed to their limits.

MOVING FORWARD:
Using i-RISC project's findings as a new measure of performance in memory and computing systems; applying proposed solutions to post-CMOS technologies, and involving industrial partners to identify ways to bring these techniques to market.



FOR MORE DETAILS

"Density Evolution and Functional Threshold for the Noisy Min-Sum Decoder"
C.-L. Kameni Ngassa, V. Savin, E. Dupraz, D. Declercq
/ IEEE Transactions on Communications, vol. 63, no. 5, pp. 1497-1509, May 2015.

VERTICAL RRAM TECHNOLOGY AND THE QUEST TO IMPLEMENT ARTIFICIAL SYNAPSES

ELISA VIANELLO
AND GABRIEL MOLAS
Scientists

EMULATING SYNAPTIC BEHAVIOR

BREAKTHROUGH:
First demonstration of a synaptic behavior with a Vertical RRAM (VRRAM) in complex neural networks.

WHY IT'S RELEVANT:
A key step toward realization of neural networks in hardware using low voltage and area efficient RRAM technologies.

MOVING FORWARD:
Full demonstrators based on RRAM for synapses and advanced CMOS logic for neurons, targeting sensory processing or autonomous systems, such as a Brain Computer Interface.

How does Leti's new vertical RRAM development suggest a novel pathway to emulating synaptic behavior?

Emerging back-end resistive memory devices (RRAM) have been viewed as optimal candidates to emulate biological synaptic behavior at nanometer scale, because their conductance can be easily modulated by applying very low biases. In addition, they can be easily integrated with CMOS-based neuron circuits.

Previous Leti projects proposed various RRAM technologies (PCM, CBRAM, OxRAM) and circuits to emulate the synaptic behavior in neuromorphic circuits. Recently, we proposed solution based on a Vertical RRAM (VRRAM) technology that offers significant area gain with respect to neural networks in planar configuration. Our VRRAM solution allows one VRRAM pillar per synapse and would integrate RRAM cells in a multi-layered, V-NAND-like structure. This is a simple and valuable 3D process to achieve high memory density.

How will this innovative combination of resistive memory and 3D integration affect future development in this field?

The next step is the fabrication of a full silicon demonstrator based on RRAM for synapses and advanced CMOS logic for the neurons. Right now, we have system-level simulation supported by data obtained with standard memory arrays. We demonstrated that neural network chips can be used for detecting patterns in complex data, and they are suitable for both visual and auditory data analysis.

RRAM technologies allow us to realize low-power circuits that are suitable for embedded systems. VRRAM could be a cost-effective and extensible technology for future mass data-storage applications. Looking further ahead, neural network chips may be used to enable the design of future sensory processing or autonomous systems, such as a Brain Computer Interface making decisions based on real-time on-line processing for rehabilitation purposes.

FOR MORE DETAILS
"Investigation of the potentialities of Vertical Resistive RAM (VRRAM) for neuromorphic applications"
G. Piccolboni, G. Molas, J.-M. Portal, R. Coquand, M. Bocquet, D. Garbin, E. Vianello, C. Carabasse, V. Delaye, C. Pellissier, T. Magis, C. Cagli, M. Gely, O. Cueto, D. Deleruyelle, G. Ghibaudo, B. De Salvo and L. Perniola / Electron Devices Meeting (IEDM) IEEE International, 17.2.1–17.2.4, 2015.

"HfO2–Based OxRAM Devices as Synapses for Convolutional Neural Networks"
D. Garbin, E. Vianello, O. Bichler, Q. Rafhay, C. Gamrat, G. Ghibaudo, B. DeSalvo, L. Perniola / IEEE Transactions on Electron Devices, 62, 2494–2501, 2015.

MIMICKING THE BRAIN'S MEMORY-STORAGE CAPABILITY FOR BETTER POWER MANAGEMENT

FREDERIC HEITZMANN
Scientist

What did your project discover about brain structure that can overcome power-management challenges in the Internet of Things?

Neural clique networks in the brain perform a powerful associative role in memory storage. Specific, cognitively significant images enable people to access detailed memories from snippets, such as remembering the end of a song after hearing its beginning.

Inspired by this highly efficient associative process in biology and brain structure, we partnered on a thesis project with a team from Telecom Bretagne, which proposed a new kind of artificial neural network. We built on that concept, providing expertise in digital design and silicon technology.

Our innovation, which enables power efficiency on a small silicon footprint suitable for IoT applications, demonstrated that features of neural clique networks can provide quick, optimal power management in electronic devices. When a piece of information, a "key", is fed into the network, the network recalls a corresponding, previously stored value in a few nanoseconds and with low power consumption.

This efficient "key-value" association makes it possible to dynamically retrieve an optimal power configuration even in a rapidly changing environment.

In fact, thanks to their brain-like properties, neural networks outperform traditional algorithms in some applications. The implementation in silicon of these wire-dominated systems created power-use challenges that Leti's 3D-design expertise overcame by significantly reducing interconnect lengths.

How will this discovery influence future R&D?

Because this technology provides a new trade-off between power consumption, area and performance for associative memory, several application fields may benefit from networks of neural cliques. Future research will explore different applications in the field of power-constraint devices or near-sensor data processing. There also are potential applications in deep learning, image classification and language processing.

NEURAL CLIQUE NETWORKS

BREAKTHROUGH:
Demonstration that features of the brain's neural clique networks can provide quick, optimal power management in electronic devices.

WHY IT'S RELEVANT:
Applying the brain's associative-memory capabilities in electronic devices creates energy-consumption and size benefits for Internet of Things applications.

MOVING FORWARD:
Leti will explore different applications for power-constraint devices or near-sensor data processing. Deep learning, image classification and language processing are also potential applications.

FOR MORE DETAILS
"Energy-efficient associative memory based on neural cliques"
B. Boguslawski, Fr. Heitzmann, B. Larras and F. Seguin / Design Automation Conference (DAC) Work-in-Progress Session, San Francisco, USA, 2015.

"Compact interconnect approach for networks of neural cliques using 3D technology"
B. Boguslawski, H. Sarhan, Fr. Heitzmann, F. Seguin, S. Thuries, O. Billoint and F. Clermidy / Proceedings of the IFIP/IEEE International Conference on Very Large Scale Integration (VLSISoC), pp. 116–121, Daejeon, South Korea, 2015.

5.

MANAGING INCREASINGLY COMPLEX SYSTEMS EFFECTIVELY AND SECURELY

FILTER-BANK MULTI-CARRIER TECHNOLOGY: MANAGING EXPLOSIVE GROWTH IN WIRELESS DATA TRAFFIC WITH TV WHITE SPACE

DOMINIQUE NOGUET
Scientist

COGNITIVE RADIO

BREAKTHROUGH:
Achieving better performance than traditional OFDM technology – without the need for costly and non-flexible filtering – FBMC's modulation is inherently spectrally localized, which reduces interference with adjacent bands.

WHY IT'S RELEVANT:
As part of an IEEE standard, the FBMC technology serves a huge demand for the growing wireless data traffic, allowing very flexible channel allocation while fulfilling regulators' rules.

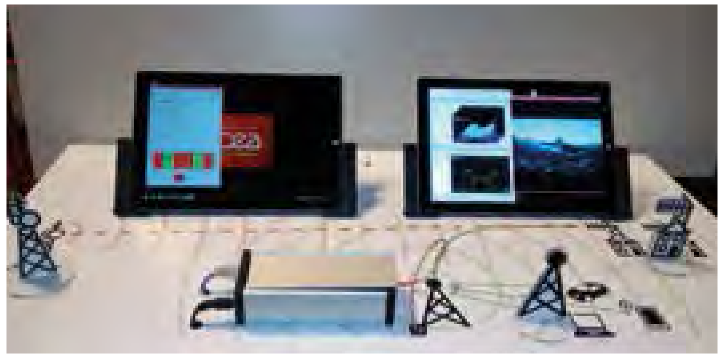
MOVING FORWARD:
Offering standardized, IP-protected implementations of FBMC-based flexible radio to network operators worldwide, while improving the MAC protocol of the standard to provide better quality-of-service support.

How will Leti's new cognitive radio technology ease the predicted bottlenecks in wireless data transfer?

Between 2016 and 2020, there will be a nearly eight-fold increase in global mobile data traffic, according to forecasts from Cisco. In the absence of additional radio spectrum availability, we will have to rely on existing frequencies to help meet that demand. Last year marked an important step towards meeting that challenge with TV White Space (TVWS), through the adoption of Leti's Filter-Bank Multi-Carrier (FBMC) technology, now implemented in an international standard.

We leveraged Leti's large wireless communication IP portfolio, including expertise in cognitive radio that dates to 2006. That helped us develop, over four years, a flexible, efficient mechanism for utilizing available TVWS spectrum without interfering with television broadcasts. It's rewarding to see our technology poised to be a potential fundamental enabler for implementation in rural broadband, campus-scale networking and wireless LANs worldwide.

The FBMC approach to flexible radio allows wireless devices to change communication parameters on the fly to utilize whatever chunks of TVWS spectrum happen to be available at any given moment. In addition to offering a 15 percent spectral-efficiency improvement over existing OFDM technology, FBMC has the even more important advantage of 9dB less interference with adjacent channels. That means it can have at least twice the range of OFDM for the same transmit power, or it can increase spectral efficiency even more (two to three times) through larger constellations, thanks to better link budget.



So, could this innovative technology be part of 5G networks?

FBMC has been implemented in the wireless communication standard IEEE 1900.7-2015. There is currently a vigorous discussion about which air interface will be selected for future 5G communication networks, and FBMC is clearly a contender. We believe that having FBMC included in an IEEE standard will increase the appeal of this approach in the 3PGG discussions on 5G. FBMC shows a very good spectral efficiency and low interference profile, which is required as spectrum is becoming more congested. In addition, the architecture designed at Leti, namely Frequency Sampling FBMC (FS-FBMC), dramatically reduces the implementation footprint compared to classic FBMC approaches.

FOR MORE DETAILS

"IEEE Standard 1900.7 for White Space Dynamic Spectrum Access Radio Systems"
S. Filin, D. Noguet, J.-B. Doré, B. Mawlawi, O. Holland, M. Zeeshan Shakir, H. Harada, F.Kojima / IEEE CSCN, Oct. 2015.

"IEEE 1900.7-2015 PHY Evaluation on TVWS Scenarios"
D. Noguet, J.-B. Doré / CROWNCOM, June 2016.

SHAPE CAPTURE SOLUTION TRACKS CHANGES IN CRITICAL INFRASTRUCTURE

NATHALIE SAGUIN-SPRYNSKI
Scientist

STRUCTURAL HEALTH MONITORING

BREAKTHROUGH:
Embedding MEMS-based, shape-capture systems in materials to monitor structural changes.

WHY IT'S RELEVANT:
Improves infrastructure safety and provides data to compare performance with models, over time.

MOVING FORWARD:
Use inertial-sensor networks distributed on a surface or in a closed space to continuously monitor the shape of 3D space.

How did Leti create a novel way to monitor structural health from the inside?

We developed an embedded, MEMS-based, inertial-sensor system that provides deformation and shape data in infrastructure such as pipes, bridges and wind turbines. Our technology and methods perform well even in harsh environmental conditions.

Building on this innovation, we worked with our industrial partner Technip to develop Morphopipe, an embedded shape-capture technology that provides 3D curvature monitoring in underwater pipes.

Our team used two fields of upstream research:
-signal processing and advanced geometrical and dual models that were part of three PhD and two postdoc projects;
-communication protocols: more sensors and higher acquisition frequencies, from research work carried out through internships and internal initiatives.

How will this innovation impact R&D in structural health monitoring?

This new way to detect damage and improve safety for structural systems can be implemented either as a short-term monitoring tool, in which our smart system is deployed for special test sessions, or as a long-term solution, in which sensors are integrated directly in the structures and provide regular data over their lifetime.

As an analytical tool, the sensors can detect and characterize damage or evolution of critical parameters within the infrastructure. This improves reliability and safety and lowers maintenance costs. In time, the sensors will provide a database of real measurements that will allow comparison with simulations or models, which will allow companies to modify and improve their models.

FOR MORE DETAILS

"Morphopipe: curvature monitoring of flexible risers with MEMS accelerometers"
M. Carmona, R. Perrier, L. Jouanet, N. Saguin-Sprynski, O. Delcroix / IWSHM, Stanford, September 2015.

"Optical Fiber sensors, MEMS accelerometers and acoustic-based non-destructive technique: three high-ends and complementary technologies for advanced SHM applications"
M. Carmona, G. Laffond, B. Chapuis, A. Paléologue, M. Billères / IWSHM, Stanford, September 2015.

FIRST NEMS IN POLYSILICON FOR 3D SENSORS ON CMOS

ISSAM OUERGHI
PhD Student

FIRST NEMS ON POLYSILICON FOR 3D SENSORS ON CMOS

BREAKTHROUGH:
Low-temperature fabrication of nanodevices with critical dimensions of ~50 nm, after back-end deposition and with back-end-compatible process flow.

WHY IT'S RELEVANT:
This technology will enable highly dense pixelated sensors, of great importance for gas sensing and mass spectrometry, and replace expensive monitoring equipment with more sensitive, portable NEMS-based devices.

MOVING FORWARD:
Integration of multi-functional sensors in various systems for embedded on-chip multi-gas analyzers or mass spectroscopy, based on arrays of NEMS resonators.

How did Leti break new ground in fabricating polySi NEMS at low temperature?

Current state-of-the-art polySi sensors are MEMS fabricated at higher temperatures, front-end compatible. Leti's breakthrough is low-temperature fabrication of nanodevices with critical dimensions of ~50nm, after the CMOS back-end deposition.

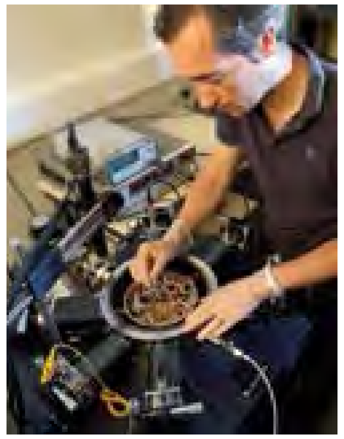
Our team developed a back-end-compatible process flow because of the thermal budget restriction imposed by the CMOS process and the back-end.

Room-temperature PVD amorphous silicon deposition and laser annealing enabled fabricating NEMS at very low temperature. Laser annealing locally provides a very high temperature – the melting point of amorphous silicon – while maintaining a low temperature for the underlying layers. The temperature of the whole process does not exceed 400°C.

How will low-temperature MEMS fabrication impact future development of nanosensors?

Leti believes 3D fabrication of NEMS following back-end deposition is a very cost-effective and compact solution for manufacturing embedded nanosensors.

A European Research Council (ERC) grant to Leti Research Fellow Thomas Ernst enabled the design and fabrication of a generic, multi-sensor design-and-technology platform for embedded on-chip multi-gas analyzers, based on arrays of NEMS resonators. The goal is to obtain high resolution and sensitivity, real-time detection and low power consumption with low-cost fabrication. Leti's innovations will help achieve that goal. A second ERC grant to Senior Scientist Sébastien Hentz is funding exploration of other disruptive applications of such 3D systems for mass spectrometry.



FOR MORE DETAILS

"Polysilicon Nanowire NEMS fabricated at low temperature for above IC NEMS mass sensing applications"
I. Ouerghi, M. Sansa, W. Ludurczak, L. Duraffourg, K. Benedetto, P. Besombes, T. Moffitt, B. Adams, P. Gergaud, C. Poulain, C. Ladner, J. M. Fabbri, D. Muyard, G. Rodriguez, G. Rabille, O. Pollet, P. Brianceau, S. Kerdiles, S. Hentz and T. Ernst / IEEE IEDM, pp. 18.3.1-18.3.4, 2015.

"High-performance polysilicon NEMS fabricated at low temperature with UV laser annealing"
I. Ouerghi, M. Sansa, L. Duraffourg, K. Benedetto, P. Besombes, K. Huet, F. Mazzamuto, I. Toque-Tresonne, C. Ladner, S. Kerdiles, W. Ludurczak and Th. Ernst / IEEE MEMS, pp. 63-66, 2016.

HOW CONTROL THEORY BOOSTS POWER MANAGEMENT IN SENSOR NETWORKS

SUZANNE LESECQ
Scientist

MANAGING POWER IN SENSOR NETWORKS

BREAKTHROUGH:
Using Model Predictive Control or Hybrid Dynamical System Control approaches to extend lifetime of sensor networks by up to 30 percent.

WHY IT'S RELEVANT:
It increases applications for the Internet of Things, while extending the lifetime of the service offered by the sensor network deployed.

MOVING FORWARD:
Proposing a truly distributed-management solution to apply these power techniques on networks with a large number of sensor nodes.

What does Leti's new application of Control Theory reveal about power use in sensor networks?

New services for smart environments such as cities, buildings, transportation and agriculture require advanced technology and new sensor architectures – with the best compromise between the service and power consumption.

Nevertheless, today, the number of sensor nodes deployed in smart buildings is larger than needed, because of the lack of coordination in building-automation systems. In other words, the independent building-automation systems don't share data.

By taking on an application-and-service perspective, we figured that some nodes could sleep, thus saving energy, with no drop in system performance. We thus worked on this optimization challenge using two approaches of control theory – model predictive control (MPC) and hybrid dynamical system (HDS) control – and we found out that the service lifetime of the sensor networks could be extended by up to 30 percent.

These results suggest exciting possibilities for many application domains, especially smart farming or monitoring of natural environments, such as forests, where nodes are far apart and only rarely need to "wake up" and transmit.

What does this discovery suggest for future R&D involving sensor networks?

The energy-management strategies proposed provide a substantial increase in sensor-network battery lifetime and, therefore, of service availability. These strategies also will provide breakthroughs at the sensor-node level. In fact, by implementing wake-up radio mechanisms at the node level, the nodes will be woken only when strictly required by the application. That would lead to a real "on-event" control in on/off sensor-node switching. As a result, the whole sensor network will be event-based, instead of sending data on a regular basis, with a huge power-efficiency gain.

FOR MORE DETAILS

"Automatic assignment of sensor node activity using Hybrid Dynamic System approach"
O. Mokrenko, C. A. Sanchez, L. Zaccarian, S. Lesecq / 54th IEEE Conference on Decision and Control - CDC'15, Osaka, Japan, 2015.

"Design and Implementation of a Predictive Control Strategy for Power Management of a Wireless Sensor Network"
O. Mokrenko, M.-I. Vergara-Gallego, W. Lombardi, S. Lesecq, D. Puschini, C. Albea / 14th Annual European Control Conference - ECC'15, Linz, Austria, 2015.

HARVESTING AIRFLOWS FOR IOT DEVICES AND BEYOND

SEBASTIEN BOISSEAU
Scientist

ELECTRET-BASED ELECTROSTATIC CONVERSION

BREAKTHROUGH:
First-ever demonstration that airflow can generate electricity through electret-based electrostatic conversion.

WHY IT'S RELEVANT:
Cost-effective airflow energy harvesters with electrostatic converters can power wireless devices – a critical feature for the IoT.

MOVING FORWARD:
Leti's research focus extends from this breakthrough towards triboelectricity, which turns dielectrics into electrets by rubbing or contact.

How did Leti come up with the idea of using low-speed airflows to power autonomous wireless sensors?

People notice breezes outdoors and cool air indoors from HVAC systems. But airflows are omnipresent in our lives. Using electrostatic converters, we showed that airflows that are barely noticeable, if at all, can be harvested as an ambient energy source with output powers in the 100µW-1mW/cm² range.

Electrostatic converters are based on a capacitive architecture made of two electrodes separated by a dielectric, e.g. by an air gap. They turn capacitance variation into electricity by using charge/discharge cycles or electrets – permanently charged dielectrics and equivalent to magnets in electrostatics – that polarize the capacitor. Combining Leti expertise in electrostatics and airflow energy harvesting, our team showed for the first time that airflow can be used to generate electricity through electret-based electrostatic conversion.

These results were built on 10 years of Leti research on ways to tap low-speed airflows for wireless sensors and actuators. Our global system approach encompassed the whole energy-harvesting chain: ambient energy, energy harvesters, power-management circuits and low-power electronic systems.

In addition to proving that these energy harvesters can work with low-speed airflows, we demonstrated that conversion efficiencies and output powers are in the same range as the ones obtainable with electromagnetic and piezoelectric devices.

This is important for the Internet of Things. Where else will this discovery lead?

The power of airflows is purely kinetic and different types of transducers can be used to convert this kinetic power into electricity. Electromagnetic transducers are predominant in state-of-the-art conversion systems and are clearly the most efficient solution for large devices. But it is also possible to use piezoelectric effects, electrostatics or even triboelectricity, which turns dielectrics into electrets by rubbing or contact.

Our research on electrostatic converters for energy harvesting is now directed towards triboelectricity.

Among ambient energy sources investigated at Leti, e.g. light, thermal gradients, vibrations, strains and shocks, airflow energy harvesting shows great innovation potential, particularly at small scale. By proving that electrostatic converters can be a valuable solution for airflow energy harvesting, we showed how to produce alternatives to standard low-power sources with simple, low-cost materials.
So, the IoT is a major application for this technology. Electrostatic converters enable the development of inexpensive, very thin transducers that are efficient at small scale – a few cubic centimeters.

FOR MORE DETAILS

"An electret-based aeroelastic flutter energy harvester"
M. Perez, S. Boisseau, P. Gasnier, J. Willemin, J.-L. Reboud / Smart Materials and Structures 24 (3), 035004, 2015.

"A cm scale electret-based electrostatic wind turbine for low-speed energy harvesting applications"
M. Perez, S. Boisseau, P. Gasnier, J. Willemin, M. Geisler, J.-L. Reboud / Smart Materials and Structures 25 (4), 045015, 2016.

FOR MORE DETAILS

"Frequency tuning with lithium niobate composite BAW resonators"
N. Boudou, J.-S. Moulet, L. Benaissa, G. Audoit and A. Reinhardt / joint IEEE International Frequency Control Symposium and European Frequency and Time Forum, Denver, April 2015.

A NOVEL ARCHITECTURE FOR MOBILE DEVICES? STAY TUNED

ALEXANDRE REINHARDT
Scientist

How did Leti researchers achieve this major advance on the true frequency-tuning front?

Tunable filters have been described as a "Holy Grail". Indeed, the Bulk Acoustic Wave (BAW) or Surface Acoustic Wave (SAW) resonators making up the many passband filters located in the RF front-ends of mobile phones exploit mechanical vibrations of piezoelectric materials to generate electric resonances. This is exactly the operation of quartz resonators used for timing applications, but transferred here to GHz frequencies. The drawback is that mechanical resonances are intrinsically fixed-frequency. To overcome this physical limitation, we proposed resonator structures capable of exhibiting a tunable mechanical resonance frequency, through the use of the so-called "acoustoelectric" effect. This means that the velocity of sound in a piezoelectric material depends on which electrical circuit this material is connected to. In principle, we add a piezoelectric "tuning layer" to a conventional BAW resonator to extend the resonant cavity by a material with a tunable equivalent stiffness. In practice, this means building a resonator made of two piezoelectric layers, instead of only one for conventional devices.

Making such a new generation of RF resonators required integrating thin films exhibiting outstanding piezoelectric properties. This is the breakthrough in which Leti scientists have been involved for more than 15 years. Leti has worked on bulk acoustic wave (BAW) resonators since 2003, which built a strong foundation in the design of acoustic components and the integration of piezoelectric materials. The actual fabrication of a demonstrator of tunable filters in 2015 leveraged the specialized know-how acquired over the past decade on the transfer of thin monocrystalline piezoelectric films.

Two specific fields of expertise that our team contributed to were essential to our results. First, the ability to understand how acoustic resonators operate and to model and design composite tunable resonators. Second, the capability to integrate and optimize thin piezoelectric films, particularly lithium niobate, which offer the outstanding piezoelectric properties required for true frequency tuning.

Building on the foundation of earlier research, we focused on developing a new generation of RF resonators that rely on bulk acoustic waves and leverage lithium niobate's piezoelectric properties. It all came together in our transfer of two piezoelectric films.

The implications are significant for 4G and 5G networks. Where do we go from here?

Current mobile phones have more than 40 RF filters, based on acoustic resonators that are fixed-frequency. The number could more than double for 4G and 5G networks – except that's just not realistic for size, cost and complexity.

We think filters capable of being tuned over a large range – say 15-20 percent of their center frequency – have the capability to totally reshape the way RF front ends in mobile devices are built. They will not only reduce the number of components, but will also support a completely new architecture. It may also impact opportunistic radio systems, or enable efficient and low-power, software-defined radios, since it provides increased flexibility and re-configurability.

This advance could lead to communication systems with lower power consumption, higher signal-to-noise ratios and/or improved linearity.

TUNABLE RF FILTERS

BREAKTHROUGH:
A tunable filter based on thin piezoelectric films of lithium niobate with outstanding piezoelectric properties.

WHY IT'S RELEVANT:
Tunable filters may totally reshape the way RF front ends in mobile devices are built. They will introduce a new class of components and allow a completely new architecture.

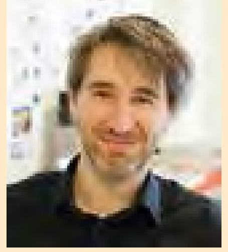
MOVING FORWARD:
Develop the technology to match loss levels, temperature stability, linearity, and rejection capabilities of commercial filters. Extend capabilities of tunable-resonators technology by introducing materials with piezoelectric properties superior to lithium niobate.

PEOPLE

AWARDS

LETI'S RESEARCH DIRECTORS
AND INTERNATIONAL EXPERTS

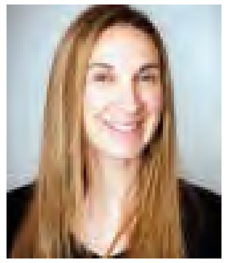
AWARDS



A SMART GAMMA CAMERA TO SPOT AND IDENTIFY RADIOACTIVE NUCLIDES

Guillaume Montémont's poster showing how Leti's portable spectrometric gamma camera allows simultaneously locating and identifying radionuclides in the field of view won **Best Poster Award at ANIMMA** 2015 in Lisbon.

The camera is based on a unique detector technology that combines spectral and spatial resolution at low cost by using dedicated signal processing known as sub-pixel positioning. Sub-pixel positioning was first integrated in a gamma camera in 2013 at Leti.



BEST PAPER AWARD FOR WORK ON ULTRA-LOW POWER ICS

Research on innovative power-reduction techniques for ultra-low-power non-volatile integrated circuits won the **Best Paper Award at ASYNC Conference** 2015. The paper was co-authored by Edith Beigné, a senior scientist at Leti, and two partners, Eldar Zianbetov of CEA/SPINTEC, and Gregory Di Pendina of CNRS/SPINTEC. Their project was a first demonstration of the implementation of the non-volatile C element and half-buffer, based on a hybrid technology that incorporates 28nm CMOS FDSOI and 40nm STT-MRAM magnetic technologies.

In their project, the team implemented non-volatile asynchronous circuits that have a quasi-zero leakage consumption, almost instant back-up and wake-up time and are robust even in unstable power-supply environments.

DOCTORAL CANDIDATE WINS BEST PAPER AWARD

PhD candidate Natalija Jovanovic won the 2015 **Best Paper Award at the IEEE SOI-3D-Subthreshold Conference.** In the paper, she presents Leti's investigation of the design architecture and the optimum resistance state values for high-endurance, high-yield energy-efficient OxRAM-based non-volatile flip-flops (NVFF) for ultra-low power applications in 28nm FD-SOI. The paper was co-authored by thesis supervisor Olivier Thomas of Leti, co-supervisor Prof. Borivoje Nikolic of the Berkeley Wireless Research Center, and thesis director Prof. Lirida Naviner, Telecom ParisTech. Natalija received her PhD in March 2016.

RECONFIGURABLE TRANSMIT-ARRAY ANTENNAS PROJECT EARNS BEST PAPER AWARD

PhD student Luca Di Palma won the **Best Paper Award at the Journées Nationales Microondes conference** in Bordeaux for his research that showed how a new architecture of reconfigurable transmit-array antennas enables a thickness reduction of 45 percent compared to standard ones.

The innovation resulted from using four focal sources instead of one, and investigating the impact of this architecture change in the radiation performance. The Leti team was the first to demonstrate this architecture, establishing it as a leader in reconfigurable transmit-array antennas. Several prototypes have exhibited innovative technical solutions and superior state-of-the-art performance.

WHERE ROBOTICS MEETS HUMANS

Andres Ospina, a PhD student in robotics, won the 2015 **Mechatronics Award at the European Mechatronics Meeting** (EMM), for his research on a tactile sensing system ready for integration in small robotics fingers or human-machine tactile interaction.

Based on 3-axis MEMs force sensors, the innovative system provides a sensitive surface capable of measuring the contact position, the force components and the torque components.

ROBERT ESTIVILL STROUD HONORED FOR ATOM-PROBE TOMOGRAPHY RESEARCH

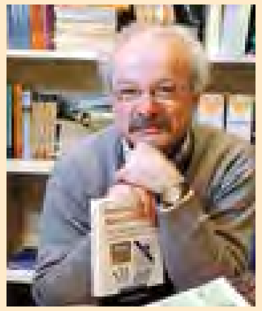
Robert Estivill Stroud won a **Presidential Scholar Award from the Microscopy Society of America** for his research that showed how atom-probe tomography can be used to characterize the chemical composition of 14nm-node devices in three dimensions with a sub-nanometer scale.

This breakthrough provides fundamental knowledge of local dopant distributions in devices, primarily boron that cannot be obtained in three dimensions by other characterization techniques. This method will be used in other research programs involving atom-probe tomography.

LETI PAPER HONORED BY IEEE ELECTRON DEVICES SOCIETY

A team of six Leti scientists won the IEEE Electron Devices Society's 2014 **Paul Rappaport Award at the IEDM Plenary** 2015 for their paper on advanced CMOS technology. The paper, "Top-Down Fabrication of Epitaxial SiGe/Si Multi-(Core/Shell) p-FET Nanowire Transistors", appeared in the April 2014 issue of IEEE Transactions on Electron Devices.

Team members were Sylvain Barraud, Jean-Michel Hartmann, Virginie Maffini-Alvaro, Lucie Tosti, Vincent Delaye and Dominique Lafond.



SIMON DELEONIBUS: A PIONEERING CAREER IN NANOTECHNOLOGY

Simon Deleonibus, former director of Leti's Components and Technology Division, was selected **Fellow of The Electrochemical Society (ECS)** in 2015. The award recognizes the scientific breakthroughs and achievements that distinguished his long career.
Early in his career, he co-invented a contact-plug technology principle, which, in its tungsten version, improved the speed and reduced the costs of microprocessors. This technology is used today as a standard process by the microelectronics industry.
In 1999, together with his team at Leti's Electronic Nanodevices Laboratory, he realized the world record for the smallest transistor and his lab pioneered numerous process modules enabling and anticipating the future miniaturization of integrated circuits.
He received the 2005 French Technologies Academy Grand Prix, an annual award given to an engineer for "major innovation, development and proof of usability by the industry".
In 2006, Deleonibus was named Fellow by the IEEE for his contributions to nanoscale CMOS device technology.

THE BOOK OF NEMS

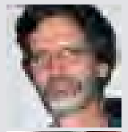
Highlighting international achievements in NEMS research and development over the years, Laurent Duraffourg and Julien Arcamone wrote a book, **"Nanoelectromechanical Systems",** which has been published in French and English. It is a comprehensive and didactical review of this field. It will help students and researchers discovering and understanding NEMS.

The book presents Leti and other organizations' successes and knowhow in NEMS to the scientific community, which may encourage students to come to work at Leti, and open pathways for Leti to join national and international consortia for academic collaborative projects.

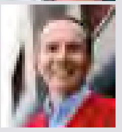
LETI AND INTERNATIONAL PARTNERS WIN BEST PAPER AWARD AT ECOC 2015

Jean-Marc Fedeli co-authored the paper, **"Monolithic Integrated Reflective Polarization Diversity SOI-based Slot-Blocker for Fast Reconfigurable 128 Gb/s and 256 Gb/s Optical Networks",** which won the award given in memory of Prof. Harm Dorren at the European Conference on Optical Communication (ECOC) 2015.
Other authors were G. de Valicourt, S. Chandrasekhar, J.H. Sinsky, C-M Chang, Y.K. Chen, M.A. Mestre, Y. Pointurier and S. Bigo, Bell Labs, Alcatel-Lucent; L. Bramerie, J-C Simon, Foton, Université Européenne de Bretagne; L. Vivien, Institut d'Electronique Fondamentale; and A. Shen, A. Le Liepvre and G.H. Duan, III-V Lab.

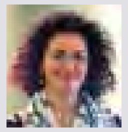
LETI'S RESEARCH DIRECTORS AND INTERNATIONAL EXPERTS



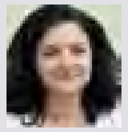
Marc Arques
International Expert
Analog electronics, X-ray image sensors



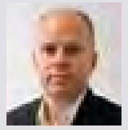
Marc Belleville
Research Director
IC design and microsystems



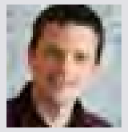
Barbara De Salvo
Research Director
Memory technologies, neuromorphic devices



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

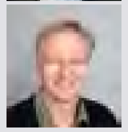


Laurent Dussopt
Research Director
Millimeter-wave wireless communication systems, millimeter-wave circuits, antennas and technologies



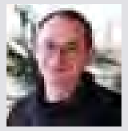
Thomas Ernst
Research Director
Logic devices and sensors

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

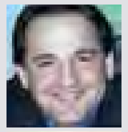


Jean-Marc Fedeli
International Expert
Silicon Photonics and optical sensors

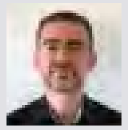
Guy Feuillet
International Expert
Optoelectronics devices, characterization and physics



Yves Fouillet
International Expert
Microfluidics, Lab-on-a-chip

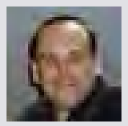


Franck Fournel
International Expert
Direct bonding techniques and hetero-structures

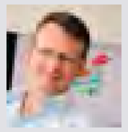


Patrice Gergaud
International Expert
X-ray characterization in micro and nanotechnologies

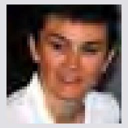
Pierre Grangeat
Research Director
Data processing for biomedical devices



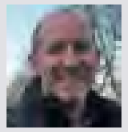
Jean-Michel Hartmann
Research Director
Epitaxy, hetero-structures for microelectronics and optics



Laurent Herault
International Expert
Communication systems, radiofrequency networks and architectures

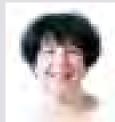


Suzanne Lesecq
Research Director
Control theory applied to SoC and power electronics, data fusion

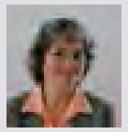


Pascal Mailley
Research Director
Biosensors, bio-electrochemistry

Francois Martin
International Expert
Microelectronic Materials and Processes



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



Corinne Mestais
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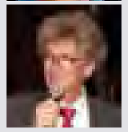
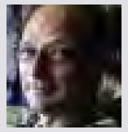
Microtechnologies for health, medical imaging

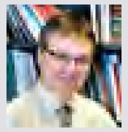
Dominique Morche
Research Director
Circuits and Systems Design for Telecommunication Applications



Hubert Moriceau
International Expert
Molecular adhesion, direct bonding, thin film transfer



Laurent Pain
International Expert
Lithography - optical, Electron beam, imprint



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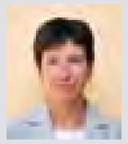
Advanced Packaging and 3D Integration



Christine Raynaud
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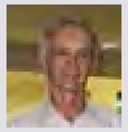
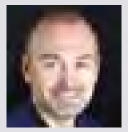
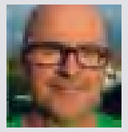
RF Technologies and Components



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



Alexei Tchelnokov
Research Director
Optoelectronic devices, photonics



Francois Templier
Research Director
Display technologies and systems

COLLABORATIONS

A DYNAMIC LOCAL ENVIRONMENT

LETI, A CARNOT RESEARCH INSTITUTE

SCIENTIFIC COLLABORATIONS

A DYNAMIC LOCAL ENVIRONMENT

A THRIVING ENVIRONMENT FOR RESEARCH

Leti, a technology research institute at CEA Tech, is located in the French Alps, in the heart of the dynamic city of **Grenoble.** Grenoble, also called the French Silicon Valley, has the highest concentration of R&D jobs in all of France: 25,000 professionals work in world renowned European research facilities, national and university research labs and industrial R&D centers. Its unique collaborative ecosystem has earned Grenoble worldwide recognition as a model for innovation. Grenoble is also home to a large international academic community with over 62,000 students of 180 different nationalities.

GIANT, Grenoble's Innovation campus for Advanced New Technologies, has become a center of globally relevant resources and assets that enable the scientific community to thrive. Offering competence, connections and capabilities in education, research and innovation, the GIANT campus fosters collaboration and creative interaction among researchers and students from universities, research labs and industry. Acting as a catalyst for much of the cooperation, CEA joined with seven other major players to launch the GIANT campus, including the University of Grenoble Alps (UGA), the National Scientific Research Center (CNRS), Grenoble's Institute of Technology (INPG), Grenoble School of Management (GEM), the Institut Laue-Langevin (ILL), which provides one of the most intense neutron sources in the world, Europe's largest synchrotron X-ray source (ESRF) and the European Molecular Biology Laboratory (EMBL). Today, groundbreaking fundamental and applied research is being carried out at GIANT in the areas of information and communication technologies, alternative energies and micro and nanotechnologies for biology and healthcare.

Within GIANT, **Minatec** is an international hub for micro and nanotechnology that brings together world-class capabilities and infrastructure for researchers, students, entrepreneurs and start-up creators. The Minatec campus is a multicultural melting pot of ambitious projects and advanced learning where exchanges and cooperation of all kinds take place. Leti is the main technological research laboratory of Minatec, interfacing both with academia and industry, bridging the path between science and innovation.

LETI IS A CARNOT RESEARCH INSTITUTE

SUSANA BONNETIER
Leti International Academic Collaborations Coordinator

The Carnot Label is granted to French public research structures dedicated to fostering innovation with industrial partners.

Marie Semeria during a Carnot institute meeting

Founded in 2006, the Carnot program was designed to recognize and support research institutes with high scientific standards, professionalism and a commitment to develop high quality research partnerships with industry, from SMEs to large companies.

Carnot institutes conduct upstream research, are capable of concurrently renewing their scientific and technological skills and engage in ambitious collaborative research that helps improve the competitiveness and growth of their business partners. A total of 60 M€ of French state funding is allocated each year to help the institutes invest in research projects that anticipate future scientific and technological needs. These projects are carried out with top-notch academic partners world-wide such as the Fraunhofer institutes, VTT, CSEM, TNO, EPFL, ETH, Stanford, UC Berkeley, Caltech, MIT, AIST, and NICT to name a few.

The 33 Carnot institutes cover a very wide range of fields, serving all the major business sectors. They represent 15% of France's public research workforce and carry out 55% of all public R&D contracts financed by corporations in France. The resulting patented inventions become novel technological solutions through co-development with industrial partners.

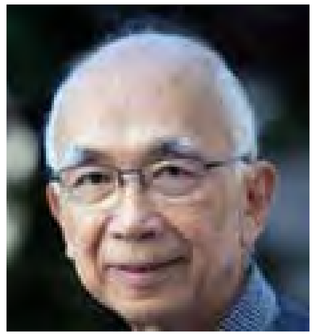
The Carnot institutes share a common charter of professional standards and are capable of championing them individually and collectively. The Association of Carnot institutes, or AiCarnot, acts as coordinator of the Carnot network. Leti's CEO, Marie Semeria, has been president of the AiCarnot since the fall of 2014.

INSTITUT CARNOT Leti

To find out more about the Carnot institutes : www.instituts-carnot.eu

SCIENTIFIC COLLABORATIONS

STANFORD UNIVERSITY



'LETI IS THE BEST CHOICE' FOR VISITING RESEARCHERS

Stanford University Prof. Yoshio Nishi came to Grenoble to head the Chair of Excellence Project funded by the Grenoble Nanosciences Foundation, and to work on the OxRAM project with Leti and IMEP-LaHC. The four-year project focused on developing a new memory technology: oxide-based resistive memories, in particular HfO2-based.

Among its achievements, the team studied the impact of alloying/doping HfO2 with other materials for improved RRAM performances. Using ab-initio calculations, they pointed out that incorporating aluminium in HfO2 results in better thermal stability of devices, due to shorter bond lengths associated with their higher atomic concentration. This has been confirmed by experiments.

Prof. Nishi, a professor of electrical engineering, spent several months in Leti's memory lab, and co-tutored a PhD student and a post-doc. The team also published eight papers.

His relationship with Leti began about 30 years ago, when he was director of R&D at Toshiba and he met Leti scientists at conferences. *"I have known Leti for a very long time,"* he said. *"The culture is very welcoming and there is a very strong work ethic. When I left the office at 7:30 p.m., oftentimes people were still working, which is very different than in the U.S. and Japan. But I also was impressed at how the French people spent their weekends focused on their families."*

He found that Leti's openness and commitment to innovation provide an encouraging setting for serious researchers.

"After lunch in the cafeteria, people gathered in a space for coffee, with a wonderful view of the snow-covered mountains," Prof. Nishi recalled. *"It was very nice to speak with Leti people in that setting and, in fact, some very interesting ideas came from those discussions. I tell my colleagues that if they have the chance to work in a foreign country, Leti in Grenoble is the best choice."*

UNIVERSITY OF SYDNEY

PROTECTING BRAIN CELLS FROM PARKINSON'S DISEASE WITH NEAR-INFRARED LIGHT

Prof. John Mitrofanis clearly remembers the day in 2015 in Clinatec's operating room when the multidisciplinary team in a pre-clinical trial proved their near-infrared light (NIr) treatment had stopped the progression of Parkinson's disease in monkey brains.

"It was a 'eureka' moment!" he said. "Light bulbs went off in our minds. We hugged each other!"

Prof. Mitrofanis, a professor of anatomy at Sydney University in Australia and a specialist in brain-tissue examination, had special reason to be thrilled. The Clinatec team was working on the NIr treatment they had discovered as a neuron-protecting agent. Applied externally, the technique worked on mice, but the thickness of the skull and the size of the brain in larger animals block that treatment.

Leti developed an implantable optical-fiber delivery system to apply the light intracranially directly on the affected monkey brain cells. Prof. Mitrofanis and Clinatec scientists confirmed that the NIr stopped PD brain-cell destruction. Preparations for a clinical trial are underway.

Prof. Mitrofanis's collaboration on PD research with Clinatec co-founder Alim-Louis Benabid goes back 15 years.

"There is no other place like Leti and Clinatec – that combines the expertise of medical and biology specialists with engineers – and brings people together for the good of a project," he said.

FRAUNHOFER INSTITUTE FOR TELECOMMUNICATIONS/ HEINRICH HERTZ INSTITUTE

LETI'S INTERNATIONAL ECOSYSTEM POWERS GLOBAL ADOPTION OF WIRELESS ADVANCES

Technology development was only part of the agenda when Berlin's Fraunhofer Institute for Telecommunications began working with Leti on millimiter-wave radio for cellular wireless networks.. To succeed, research advances had to be easily adoptable by network companies worldwide and the Leti-Fraunhofer partnership provided the ideal means of ensuring this.

"We had extensive discussions with partners on integration into existing networks; they were very willing to talk because Leti and our group were strong partners," explained Thomas Haustein, head of Fraunhofer's Wireless Communications and Networks Department. *"Leti has an international ecosystem and is well connected outside Europe. That's essential for technology dissemination, and we've seen it in other joint 5G-related projects."*
The millimeter-wave project received substantial standardization contributions from Intel and Orange in Europe, and KDDI and Panasonic in Japan. *"That created momentum, and paved the way for integration after the research was completed,"* he noted.

To be sure, the project partners' complementary technical expertise was critical – Fraunhofer's deep knowledge of lower levels in the communications stack and antenna propagation fit perfectly with Leti's expertise in radio resource sharing, modeling and measurement.

"Working with Leti has a special momentum, because of its broad cultural background," Haustein said. *"Going to the next level of forming a European-Asian consortium requires embracing cultural diversity and understanding of how to make things work, and Leti is a great partner for this."*

MIT – INTERNATIONAL SCIENCE AND TECHNOLOGY INITIATIVES

MIT STUDENTS FIND CHALLENGING REAL-LIFE PROJECTS AND A WORK-LIFE BALANCE AT LETI

Students from MISTI – a MIT's flagship education program – hadn't realized how much they like doing research at the nanoscale until they went to Leti. According to Molly Schneider, MIT-France Program manager, the custom-tailored internship experience at Leti helped her students expand their academic focus and envision research as a career.

Working on projects at Leti has made MIT students appreciate their potential. *"They want to solve challenges and feel that they are contributing"*, notes Molly, *"and being part of a research team is a powerful experience. Projects at Leti are international and multidisciplinary, which is not the case everywhere"*.

At Leti, students are in the academic, industrial and large research infrastructure environment of Grenoble. As part of GIANT's internship program, they are exposed to research taking place in other laboratories and get involved in social and cultural events. *"There is a real commitment to give the students an immersive experience"*, says Molly, *"and the support offered by GIANT is unique in Europe"*. Students also appreciate France's work-life balance. They see that people work hard to move their projects forward and are still able to share lunch with friends and go on vacation.

Leti has been hosting MIT students since 2008. These have developed a long-lasting relationship with their supervisor, a real mentor in most cases. "Access to the nanotech equipment at Leti is another plus", adds Molly. "One student found herself working in seven different lab spaces including clean rooms, biology and chemistry labs and machine shops!" During one of Molly's visits to Leti, a student shared his enjoyment with what he was doing. "His excitement was palpable and that is what I feel most when I come to Grenoble".

POLITECNICO DI MILANO

THINKING BIG AT LETI: SUCCESSFUL COLLABORATION IN OPTICAL TOMOGRAPHY

The Department of Physics at Politecnico di Milano (PoliMI) and Leti are developing new optical imaging approaches combining innovative detectors developed at the university, and Leti's new time-resolved diffuse optics approaches.

"The key technological advance involves applying time-domain detection as a way to go deeper into tissue and get images with functional and chemical information for clinical diagnostics," said Prof. Antonio Pifferi at PoliMI, who leads the Department of Physics' collaboration with Leti. *"We want to extract information coming from deeper regions in the brain, for instance, or from suspect lesions in the breast."*

Prof. Pifferi said that scientists at Leti have "an extremely high level" of expertise and professionalism, adding that Leti's culture encourages people to think beyond the immediate projects, with a strong focus on industrial and clinical translation.

"Our collaboration actually goes beyond the professional aspect. When I come to Leti in Grenoble, I always feel like a family atmosphere, interactions are friendly and easy-going," he said. *"In addition to the ongoing work, we discuss new project ideas and engage with new fascinating concepts – and this is what eventually makes research enjoyable and fruitful."*

TELECOM BRETAGNE

FROM BASIC RESEARCH TO THE IOT: 'REALLY GOOD WORK AND FIRST APPLICATION OF THE THEORY'

Prof. Claude Berrou from the Graduate School Telecom Bretagne teamed up with Leti researchers on a PhD project that built on the school's work in artificial neural networks. Their innovation, which enables power efficiency on a small silicon footprint suitable for Internet of Things applications, demonstrated that features of neural clique networks can provide quick, optimal power management in electronic devices.

Prof. Berrou, who previously developed a new family of quasi-optimal error-correction codes called turbo codes, said Leti's expertise and its emphasis on applications make it a top institute for visiting researchers.

"I am deeply interested in applications for research," he explained. *"Previously in France, technology was not considered important for academic researchers. But this has changed now, and academics are increasingly looking at applied science and technological applications."*

Leti shares this vision and opens its doors to scholars interested in putting basic research to work to improve people's lives.

"I'm very pleased with the experience of this project at the scientific level. It was really good work and the first application of the theory," Prof. Berrou said. *"We had several publications, and thanks to these, we proved the importance and the success of our theories."*

FORSCHUNGSZENTRUM JÜLICH (FZJ)

LETI STAYS PLUGGED IN TO BASIC RESEARCH IN THE GRENOBLE ECOSYSTEM

For Dan Buca, a group leader and senior scientist at FZJ, R&D that has an impact takes more than scientific knowhow. It must also be based on a foundation of strong relationships among researchers. Such partnerships are at the heart of Leti's culture.

"The personal relationships and the ease of collaborating with Leti brings success to our projects," he said. "They listen. They don't start sentences with 'no, this is complicated' or 'we first need to get a project number', and so on. They first try to see if the problem can be solved and then they look for ways to do just that!"

CEA and FZJ, a member of the Helmholtz Association of Institutes, have had cooperation agreements since 2008 to explore common areas of interests such as high-performance computing, new energy technologies and nanotech materials science.

Dr. Buca praised Leti's unicity and said that it is "the only research institute in Europe that combines a strong focus on basic research, whose payoff may or may not come for many years, with a commitment to bring new technologies to market in the near term."

He added that *"What Leti still has, and other major research groups in Europe seem to have lost, is the freedom of playing in both the fundamental research and applied research arenas."*

Dr Buca gives the Grenoble Research ecosystem some of the credit for that. *"Basic research in Grenoble's ecosystem keeps Leti active in prospective developments that could have a strong impact in 10 years. Working with other research institutes is the best way to stay informed about on-going basic research and its technological potential,"* Dr. Buca said.

POLITECNICO DI TORINO

'CROSS-FERTILIZATION' PREPARES GRADUATE STUDENTS FOR RANGE OF PROJECTS

Politecnico di Torino, one of Italy's top engineering and IT universities, takes pride in its educational programs, international appeal (its students represent over 100 countries) and extensive research connections with technology-driven companies. Those qualities are all reflected in its collaboration with Leti, now in its fourth year, which enables master's and PhD students to spend six months working with research teams in Grenoble.

"It gives us excellent access to technologies, and helps calibrate what we do in our own programs," said Professor of Computing Engineering Massimo Poncino, who has placed a number of students in the program. "Leti is tightly connected with its local industrial partners, who work on the very latest advances, and it's important for our students to see their priorities in circuit logic, digital systems and other areas."

The program has become a source of cross-fertilization, with students bringing back perspectives and knowledge that have been immediately helpful on other projects, Poncino said. Several participants have coauthored conference and journal publications, and one participated in a patent filing for a circuit that can reduce power consumption by relaxing its precision depending on working conditions.

A big plus: most Politecnico students work in Leti's small laboratory research teams of two or three scientists who are permanent staff, so they get immediate responsibility for achieving research goals.

"Sometimes with other labs, people might only get an hour a week with colleagues. At Leti, you get feedback and interactions every day – it's more like working in an experimental office," Poncino explained. *"Leti and Politecnico believe strongly in this very successful program."*

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Results here reported correspond to research activities of Leti's scientists and students during the year 2015

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