Photo Sergio Grazia

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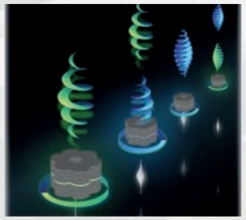
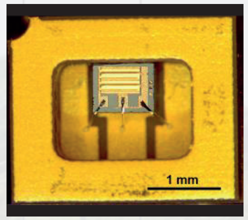
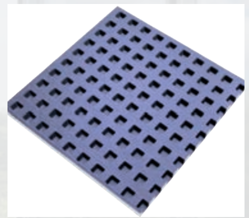
HIGHLIGHTS 2019 - *Centre de Nanosciences et de Nanotechnologies (C2N)*

Highlights 2019

C2N
Centre de Nanosciences & de Nanotechnologies







Editorial

I am delighted to share with you some of the major scientific accomplishments of C2N in 2019, reported in this booklet. They cover the entire value chain from basic science research to its applications, one of the hallmarks of the C2N's identity, but also highlight the recognition by our peers with the presentation of awards to our researchers.

2019 was the first full year of activity of the C2N in its new building, that could host a number of workshops, seminars and colloquia. In total, around 3000 people visited the C2N during this first year. It helped at positioning the C2N in its local, national and international environment. We can especially highlight the workshops «Micro-Nano-Photonics Days» and «Quantum and Neuromorphic Technologies Meet», and the French-US symposium «Nanoelectronics», which covered photonics, quantum photonics, neuromorphic and nanoelectronics topics with speakers at the best level.

2019 was also the year the series of C2N Colloquia started, inaugurated by Prof. Alain Aspect, followed by Nobel Prize Prof. William Phillips. The C2N Colloquia are designed to invite leading outstanding personalities for a scientific presentation, followed by a privileged discussion with PhD students and postdocs only, where they can freely question the guest about his research, his career, his advice, etc.

2019 was also important in term of scientific activities, even if it didn't reach yet its full capacity, the highlights listed in this booklet show you a number of impressive results. Some world state-of-the-art premieres were obtained in fundamental quantum optics, quantum nanoelectronics as well as in applied photonics, with a prototype device for photovoltaïcs applications. We can also count some highlights in nanotechnology, in nanobiofluidics or in applied nanoelectronics with the startup Spin-Ion Technologies awarded with a *Grand Prix i-Lab* 2019.

This new year that begins is expected to see the rise to its normal operating regime of the largest academic micro-nano-technology facility in France, hosted by C2N and belonging to the national nanofabrication network Renatech. In this context, C2N sits its role of flagship laboratory for research in nanoscience and nanotechnology largely open to academic and industrial partnerships.

I wish to express my profound gratitude to all the contributors to the present «Highlights 2019», in particular the researchers and engineers who contributed to the writing/editing/translating of each piece of news and with a special thanks to the C2N Communication team for their valuable contribution to this booklet.

Giancarlo Faini,
Head of C2N

Summary

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Silicon photonics, integration and hybrid photonics

Centre de Nanosciences & de Nanotechnologies C2N

Date:
February 20, 2019

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C2N News

Reference:
M. Berciano and al,
Communications Physics
(Oct. 2018)

Linear electro-optic effect in a centrosymmetric semiconductor

Researchers from C2N demonstrated a high-speed Pockels effect in strained silicon waveguides, clearing the doubts raised over the last decade on its existence.

The explosion of data demand imposed new requirements in terms of data transmission rate and power consumption that are more and more difficult to meet without greatly increasing the power consumption in data centres and hot spots of communication networks. In this context, silicon photonics is considered as the most adapted solution to address these complex issues by replacing power hungry on-chip metallic interconnect by silicon-based photonics links. One key step consists in the conversion of data carried by an electric signal to an optical signal by means of an electro-optic modulator. A lot of efforts were put into the conception of high-speed and low power consumption modulators while reducing fabrication costs and complexities by exploiting microelectronics-based materials including silicon and germanium.

An ultrafast electro-optic effect used in most fibre communication circuits such as lithium niobate modulators is the Pockel effect, relying on the second order non-linear susceptibility. However, silicon being a centrosymmetric material, it cannot exhibit Pockels. Nonetheless, this limitation is relaxed by applying deformations to the silicon lattice by means of stress in order to break its inversion symmetry. Numerous theoretical and experimental studies were recently reported to demonstrate and quantify the Pockels effect in strained silicon. But, the semiconductor nature of silicon tremendously complicates the analysis of the Pockels effect, whose existence was questioned in strained silicon and became a source of controversy. Indeed, free carriers in silicon waveguides and at the interfaces induce a strong electro-optical signal, thereby screening the signature of the Pockels effect.

For a few years, a team at C2N has been studying the theoretical aspects of the Pockels effect in strained silicon. In this work, the researchers experimentally demonstrated the clear presence of a Pockels-based electro-optic modulation signal at frequencies higher than 20GHz to stem free carriers effect. In addition, the researchers developed a multiphysics model to describe the experimental results and extracted the second-order nonlinear electric susceptibility tensor quantifying, among others, the ability for a material to give rise to the Pockels effect. Particularly, the spatial distribution of all optical nonlinear components in strained silicon waveguides has been determined for the first time.

Dependences on both the propagation direction of light within the silicon lattice and the level of stress applied to silicon were also observed and analysed. This work is published in Communications Physics (Nature Press).

The results presented in this article pave the way for the optimization of efficient electro-optic silicon modulators based on Pockels effect.

**This work has been performed in the framework of ERC Popstar project dedicated on the development of strained silicon photonics.*

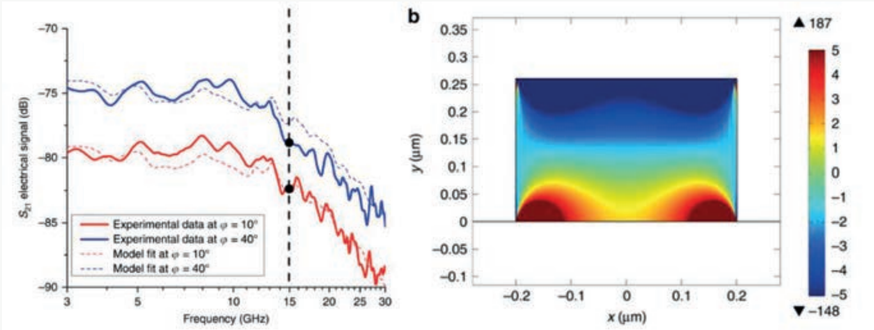

Figure: Left: Comparison between theoretical and experimental electro-optic responses, between 3 GHz and 30 GHz for different light propagation directions. A good agreement between experimental data and the theoretical model was achieved. Right: Spatial distribution, in a strained silicon waveguide, of the main component of the second-order nonlinear electric susceptibility tensor responsible for the measured Pockels effect. © C2N/M. Berciano

Reference

Fast linear electro-optic effect in a centrosymmetric semiconductor,
M. Berciano, G. Marcaud, P. Damas, X. Le Roux, P. Crozat, C. Alonso Ramos, D. Pérez Galacho, D. Benedikovic, D. Marris-Morini, E. Cassan and L. Vivien
Communications Physics 1: 64 (2018), Nature Press
DOI: https://doi.org/10.1038/s42005-018-0064-x

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Centre de Nanosciences & de Nanotechnologies

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C2N News

Reference:
D. Oser and al,
Laser & Photonics Reviews
(July 2019)

Experimental demonstration of an on-chip, passive high-rejection filter in silicon

Physicists at C2N and Institut de Physique de Nice have found a simple and generic strategy to overcome one of the major limitations in the fabrication of on-chip filters. They experimentally demonstrated an optical rejection exceeding 80 dB, without the need for any active tuning, enabling photonic noise suppression in quantum circuits.

Quantum information science holds an immense potential for high-impact applications like data processing or secure communications. In this context, silicon photonics is considered as an enabling technology for the scaling up of these quantum applications, as it would allow the low-cost and large volume fabrication of smart quantum chips implementing multiple functionalities. In these circuits, the first step is to generate entangled photon pairs from a strong optical pump through optical nonlinear effects in silicon. Then, these pairs can be manipulated, taking advantage of the high-performance building blocks already available in silicon photonics technology. However, the performance of on-chip silicon-based quantum circuits is hampered by photonic noise arising from the substantially higher pump intensity compared to that of the photon-pairs. On-chip suppression of this noise remains a challenge. Indeed, the only demonstration of on-chip pump rejection in a silicon quantum circuits has required cascading of two chips. This is mainly due to the limited rejection of state-of-the-art silicon filters.

A myriad of optical filters has been demonstrated for the silicon photonics technology, including cascaded resonators, interferometers and Bragg grating filters, which are able to reflect particular wavelengths of light and transmit all others. Although theoretical designs can achieve remarkably large rejection levels, practical implementations is typically limited to 30-60 dB rejection by fabrication imperfections. Even small deviations in device dimensions can produce large phase errors resulting in destructive interferences that distort the filter response. This effect is accentuated in silicon photonics filters by the high-index contrast between the silicon and the cladding. Active phase tuning can partially alleviate this detrimental effect at the cost of increased fabrication and operation complexity.

In a work published in July 2019 in *Laser & Photonics Reviews* journal, a team of researchers at C2N Photonics Department in collaboration with I*nstitut de Physique de Nice*, presented a new strategy for the on-chip implementation of high-rejection silicon filters, obviating the need for active tuning. The proposed approach exploits modal engineering in waveguide Bragg gratings to make the device immune to phase errors. Bragg filters rely on a periodic corrugation in the waveguide to reflect back the light at a specific wavelength, thereby implementing a notch in the transmission spectrum.

While conventional Bragg gratings couple back-reflections in the fundamental waveguide mode, in this novel approach, the waveguide gratings are shaped to couple the Bragg back-reflections into a high-order spatial mode. Then, different Bragg gratings are separated by single-mode waveguides. Back-reflections, propagating in a high-order mode are radiated away in single-mode waveguides interconnecting adjacent filter stages, precluding destructive interferences. It turns out that such simple and generic strategy overcomes one of the major limitations of on-chip filters.

The filters were fabricated in the C2N Technology Facility, and the experimental characterization was performed at C2N and Institut de Physique de Nice. The complementary skills of both teams were key to experimentally demonstrate an optical rejection exceeding 80 dB, enabling photonic noise suppression in quantum circuits. Moreover, this is the highest rejection ever reported for a passive silicon filter. We foresee that these high-rejection optical filters will expedite the development of a new generation of high-performance nanophotonic quantum circuits exploiting key advantages of silicon photonics.

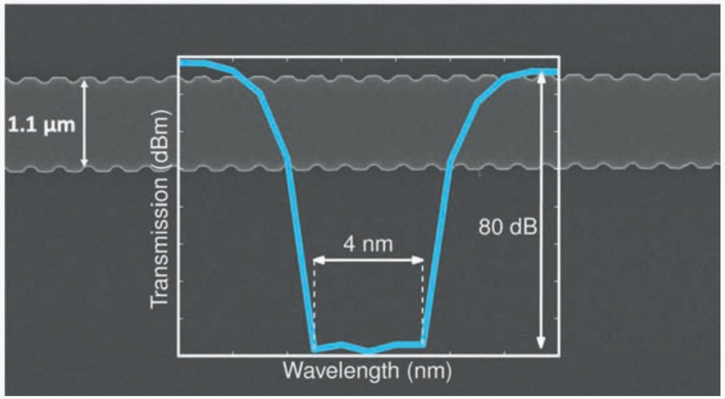

Figure: Scanning electron microscope image of fabricated Bragg filter (background SEM picture) and measured transmittance showing record 80 dB rejection (graph). © C2N / C. Alonso-Ramos & al.

Reference
Coherency-broken Bragg filters: overcoming on-chip rejection limitations,
D. Oser, F. Mazeas, X. Le Roux, D. Perez-Galacho, O. Alibart, S. Tanzilli, L. Labonte, D. Marris-Morini, L. Vivien, E. Cassan and C. Alonso-Ramos
Laser & Photonics Reviews (2019)
DOI: https://doi.org/10.1002/lpor.201800226

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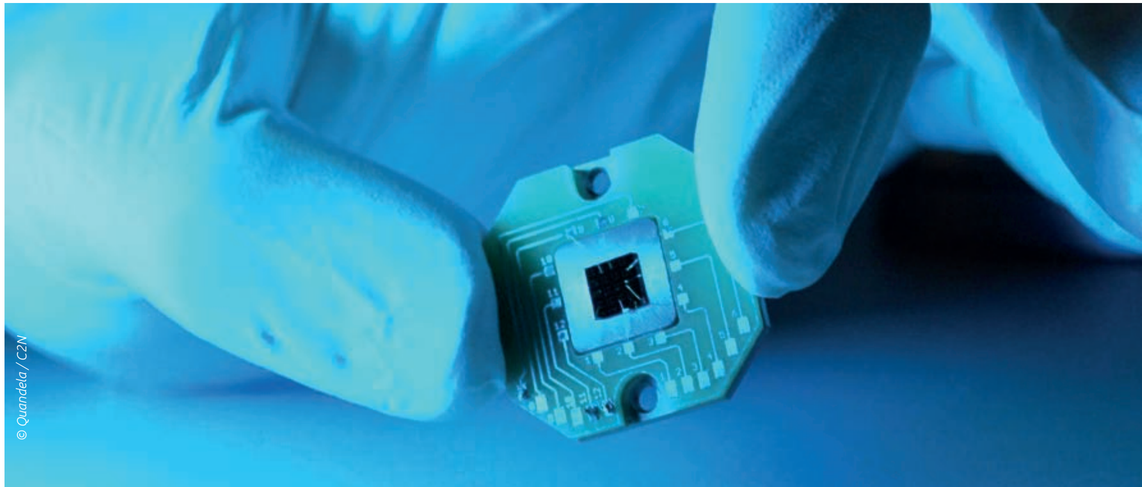
Quantum and Nonlinear Photonics



Centre de Nanosciences & de Nanotechnologies

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C2N News

Reference:
N. Carlon Zambon and al,
Nature Photonics
(March 2019)

A microlaser emitting helical light

Researchers recently demonstrated the realization of an integrated microlaser based on a novel design that allows emitting light in chiral modes, thus producing corkscrews of light.

An object is said to be chiral if it can be distinguished from its mirror image. Due to their helical shape, corkscrews are particularly good examples. Such chiral objects are ubiquitous in nature, from rotating galaxies to the DNA double helix. Chirality of light can be defined when its phase winds along its propagation axis. In the 1990s, it was recognized that harnessing such a chiral feature of light fields, called the orbital angular momentum (OAM), could be technologically advantageous. Indeed OAM represents an unbounded degree of freedom, as the phase front can theoretically wind an arbitrary large number of times within an optical period. It therefore offers a drastically enlarged basis for encoding information in comparison to the commonly used polarization states of light, which are limited to a two-dimensional basis. Multiplexing information in such a higher-dimensional basis would offer the possibility to drastically enhance the efficiency of both classical and quantum information protocols. Furthermore, transferring such large values of angular momentum to massive particles is a powerful asset for optical manipulation schemes at the atomic scale (i.e. atomic tweezers).

Researchers from the *Centre de Nanosciences et de Nanotechnologies* (C2N) in Palaiseau, together with collaborators from Laboratory PhLAM in Lille and from Institut Pascal in Clermont-Ferrand, have reported the demonstration of a novel integrated laser architecture, where light is emitted in a chiral state, thus producing corkscrews of light (see image). The disruptive advantage of this microlaser lies in the possibility of controlling the orientation of the corkscrew (from clockwise to counter clockwise) by simple optical means. Their work has been published in *Nature Photonics.*

In order to generate these chiral states of light, the researchers have used an approach based on two main ingredients. First, they fabricated a hexagonal laser cavity formed from six coupled micropillars. As a result of the rotational symmetry of their device, the resonating modes present OAM with well-defined values. Secondly, in order to favour emission from either clockwise or counter-clockwise optical modes, which requires breaking time-reversal symmetry in the system, they took benefit of an engineered interaction between the polarization and OAM of light. This interaction couples the OAM and the polarization of the photon modes. This coupling allows generating a lasing emission with a net chirality by using a circularly polarized optical pump. As a result, this novel microlaser emits clockwise or counter-clockwise coherent light depending on the circular polarization of the optical pump.

The achieved result makes it possible to imagine polaritonic integrated devices of a few microns in length, whereas their photonic equivalents have dimensions of the order of a hundreds of microns. The horizontal, guided geometry is also appealing because it is easy to fabricate and to integrate in two-dimensional optical circuits.

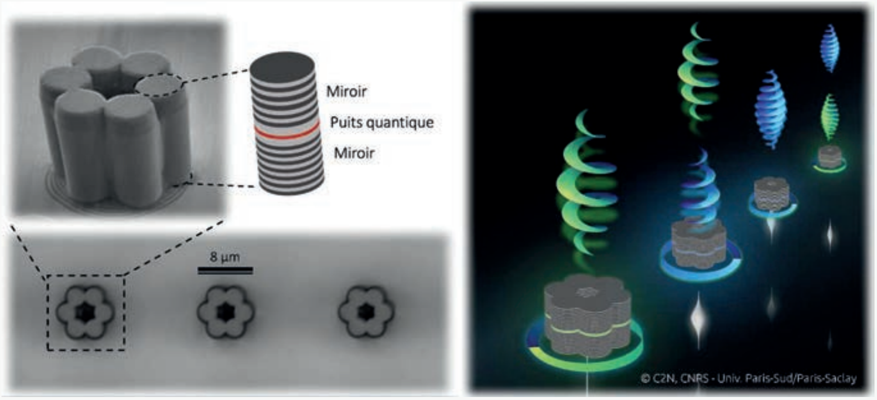

Figure: Scanning electron microscopy image of hexagonal laser cavities formed from six coupled micropillars (fabricated at C2N); Left: image schematically shows semiconductor layers forming each pillar with two mirrors and an active region consisting of a quamtum well; Right: artistic representation of light emitted in chiral states from hexagonal cavities, thus producing corkscrew of light. © C2N / N. Carlon Zambon

Reference

Optically controlling the emission chirality of microlasers,
N. Carlon Zambon, P. St-Jean, M. Milićević, A. Lemaître, A. Harouri, L. Le Gratiet, O. Bleu, D. D. Solnyshkov, G. Malpuech, I. Sagnes, S. Ravets, A. Amo and J. Bloch
Nature Photonics, volume 13, pages 283–288 (2019)
DOI: https://doi.org/10.1038/s41566-019-0380-z / Available on arXiv

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C2N News

Reference:
J. C. Loredo and al,
Nature Photonics
(2019)

Generation of light in a photon-number quantum superposition

Physicists at C2N have demonstrated for the first time the direct generation of light in a state that is simultaneously a single photon, two photons, and no photon at all. They showed that the same kind of light emitters used for decades are also able to generate these quantum states, and expect that this holds true for any kind of atomic system.

Quantum superposition is a property of quantum physics that allows objects to exist simultaneously in different states. A famous theoretical example is the Schrödinger's cat which is both dead and alive. Let us imagine an object trying to find the exit of a maze. In the classical realm, it will try every path, one at the time, until it finally finds the exit. In the quantum world, however, superposition allows the object to try all different paths simultaneously, therefore finding the exit much faster. For light, superposition has been shown in several of its properties. For instance, in its polarization, where the electromagnetic field of a single-photon oscillates both vertically and horizontally; or in path, taking upon all possible trajectories inside interferometers, the photonic versions of a maze. Superposition has been achieved even in time, with photons existing simultaneously at earlier and later moments.

However, creating light in a state that is simultaneously a single photon, two photons, or no photon at all, in other words a quantum superposition of "photon-numbers", has remained elusive. Some complex experiments had already managed to obtain these superposition states a few times, but it had never been achieved on demand, which means with success at every experimental run. Moreover, it was not known whether direct emitters of these states existed. In a work published in Nature Photonics in August 2019, researchers at the *Centre de Nanosciences et de Nanotechnologies* – C2N (CNRS / University Paris-Saclay) and the *Institut Néel* (CNRS, Grenoble), have demonstrated for the first time the on-demand generation of light in a quantum superposition of photon-numbers.

The researchers studied the emission of an artificial atom, a semiconductor quantum dot inserted in an optical microcavity, a technology that has recently provided the most efficient single photon sources. By performing a coherent excitation of the quantum dot with optical pulses, they showed that the quantum coherence in the atomic state is preserved through the process of spontaneous emission and imprinted onto the emitted photonic state, generating a quantum superposition of zero, one, and two photons.

Such observations, never seen before in any atomic system, demonstrate that artificial atoms like quantum dots are now controlled to such a point that they behave as the systems described in textbooks. These new quantum states of light based on the coherent superposition of photon-number states open exciting paths for designing and implementing new schemes in quantum communication and computation.

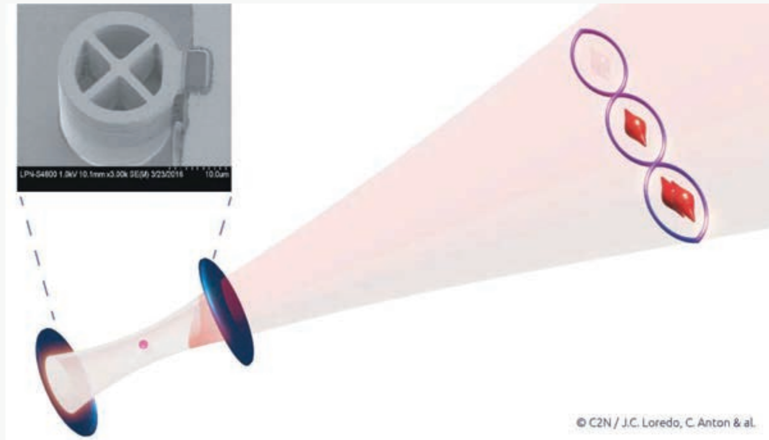

Figure: Schematic representation of the experiment. A quantum dot coupled to an optical microcavity (in inset a real image of the device) emits light in a state that is simultaneously a single photon, two photons, and no photon at all: a quantum superposition of photon-numbers. Copyright C2N / J.C. Loredo, C. Anton & al.

Reference
Generation of non-classical light in a photon-number superposition,
J. C. Loredo, C. Anton, B. Reznychenko, P. Hilaire, A. Harouri, C. Millet, H. Ollivier, N. Somaschi, L. De Santis, A. Lemaître, I. Sagnes, L. Lanco, A. Auffeves, O. Krebs & P. Senellart
Nature Photonics (2019)
DOI: https://doi.org/10.1038/s41566-019-0506-3

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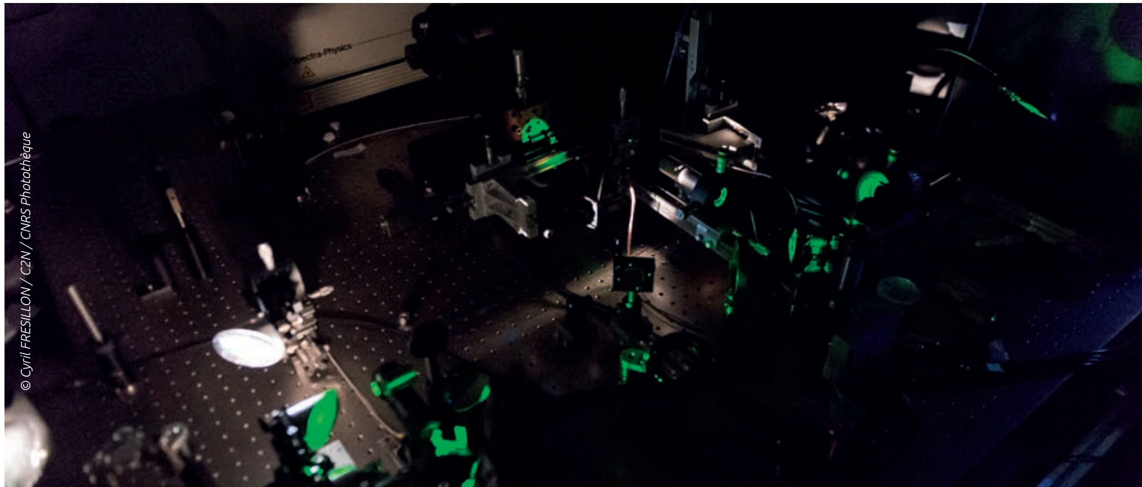
Electro-Optomechanics & Nanophononics



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C2N News

Reference:
M. Esmann and al,
Optica
(2019)

Confined nanoscale sound controls light in a microresonator

Researchers demonstrate a semiconductor device for the tailored generation of Brillouin signals in the ultrahigh 100GHz-THz regime.

When traversing a solid material such as glass, a light wave can deposit part of its energy in a mechanical wave, leading to a color change of the light. This process called "Brillouin scattering" has important technical applications. Long-range optical data transmission on the internet, for example, relies on amplifiers generating mechanical waves in an optical fiber via a strong laser light field. The frequencies at which mechanical waves can be optically excited, and hence the optical spectra that can be generated through Brillouin scattering, are usually dictated by the material properties. So far, this has limited the range of possible applications.

Researchers from the *Centre de Nanosciences et de Nanotechnologies* - C2N (CNRS/Université Paris-Saclay) have recently demonstrated a micropillar made from alternating layers of two different semiconductor materials that constitutes a novel device to control light with sound. The micropillar device can shape an optical spectrum through Brillouin scattering almost completely at will. Their work[1] was published in the journal Optica.

The main trick behind the device's versatility is to control light and sound by separate parts of the device. In the state-of-the-art technology facility of the C2N, the researchers fabricated micropillars in which the inner layers, with extremely fine thicknesses in the range of a few nanometers, constitute a resonator for sound waves at particularly high frequencies of 300GHz. This resonator is embedded between thicker layers, which resonantly confine light. Since light and sound are confined in the same spatial region in all three dimensions of space, the device is also unusually efficient in Brillouin scattering generation in comparison to its size.

In their study, the researchers devise a novel optical technique to detect and optimize the generated Brillouin spectra under the influence of thermal effects. They are, however, sure that the impact of their discovery goes well beyond that: Micropillar resonators can be directly interfaced with optical fibers. Therefore, they are a promising platform to integrate Brillouin light sources with optical nano-circuitry on a chip. The researchers also point out that their device may be combined with active lasing media and could even be improved to reach the regime of active acoustics, that is, the mechanical wave analog of a laser.

[1] *The research was funded in part by the ERC, the French ANR, the French Network of nanofabrication facilities RENATECH and the German Research Foundation DFG.*

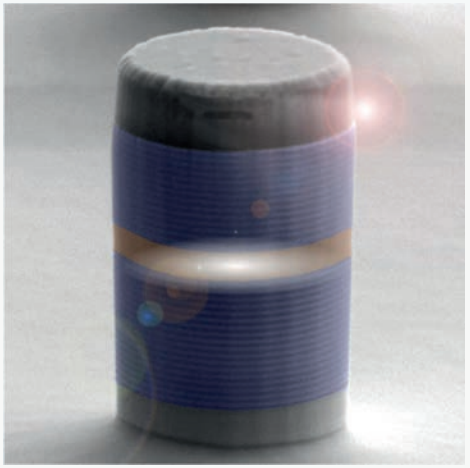

Figure: Scanning electron micrograph of the novel Brillouin scattering micropillar device. The diameter is 4.5 micrometers. The false colors mark the inner part confining high frequency vibrations (in orange) and the outer part confining light (in blue).

Reference

Brillouin Scattering in Hybrid Optophononic Bragg Micropillar Resonators at 300 GHz,
M. Esmann, F. R. Lamberti, A. Harouri, L. Lanco, I. Sagnes, I. Favero, G. Aubin, C. Gomez-Carbonell, A. Lemaître, O. Krebs, P. Senellart and N. D. Lanzillotti-Kimura
Optica (2019)
DOI: https://doi.org/10.1364/OPTICA.6.000854

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C2N News

Reference:
I. Ghorbel and al,
APL Photonics
(2019)

A compact optomechanical gigahertz oscillator made of a piezoelectric III-V semiconductor

A team of physicists at C2N and Thalès Research and Technology have demonstrated an optomechanical oscillator, based on an ultra-compact bichromatic one-dimensional crystal, able to operate at 3 GHz at room temperature.

Oscillators are devices able to produce a periodic signal of high purity, and are used in many industrial fields and many everyday applications. However, they generally operate poorly at low frequencies, with poor phase stability or necessitating a fairly large architecture. For applications in the fields of telecommunications or satellite positioning, oscillators in the GHz frequency range are key basic elements. Demonstrating a compact oscillator, able to operate at these frequencies while maintaining high stability, has remained a challenge until now. Optomechanical resonators, which exploit the interaction between an optical mode and a mechanical mode, confined and collocated at the center of the resonator, have been actively studied in recent years and can address all of these challenges.

In this context, researchers at C2N, in collaboration with Thalès Research and Technology, developed optomechanical structures made of InGaP* using a concept of nanoengineering based on a bichromatic one-dimensional optomechanical crystal. The optical reading of the Brownian motion of these ultra-compact structures under atmospheric conditions makes it possible to highlight mechanical modes close to 3 GHz, with a mechanical quality factor at the state of the art (a few thousand). These results have been published in *APL Photonics.*

Under these conditions and for a free-running resonator (without external feedback loop), self-sustained optomechanical oscillations are systematically obtained directly at the mechanical frequency with a low driving optical power threshold of the order of 40 μW. The linewidth of the mechanical mode is then reduced to 100 Hz. Indeed and in accordance with the phase noise measurements, the spectral purity of the mechanical mode is enhanced by about a factor 10000.

These optomechanical crystals have a unique potential to become ultra-compact stable microwave oscillators with properties comparable to the state of the art but directly in the GHz frequency range and without resorting to frequency multiplier stages, with the advantage of providing an additional optical output, convenient for on-chip signal distribution. Moreover, these devices made of a piezoelectric material can be equipped with piezoelectric transducers and hybridized on a photonic silicon circuit in order to be used for microwave conversion in optics and for more elaborate miniaturized optoelectronic oscillators with self stabilization schemes.

** Semiconductor in Indium / Gallium / Phosphide. The low optical losses due to low two-photon absorption and its piezoelectric properties make it a valuable material for optomechanics and other photonics applications.*

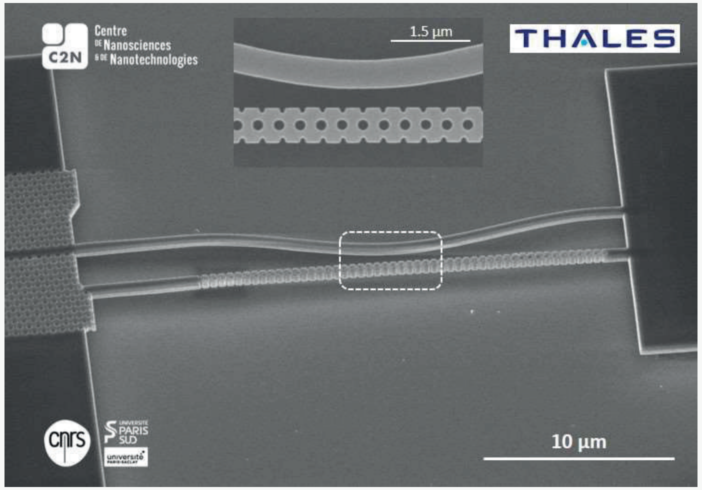

Figure: (Side view) Scanning electron microscope image of the suspended optomechanical cavity. (View from above) Focus on the center of the cavity confining both optics and mechanics. The holes in the center and the indentations at the edges of the beam with a different periodicity induce the bichromatic character of the confinement. Copyright C2N/Thalès TRT

Reference

Optomechanical Gigahertz Oscillator made of a Two Photon Absorption free piezoelectric III/V semiconductor,
I. Ghorbel, F. Swiadek, R. Zhu, D. Dolfi, G. Lehoucq, A. Martin, G. Moille, L. Morvan, R. Braive, S. Combrie & A. De Rossi
APL Photonics (2019)
DOI: https://doi.org/10.1063/1.5121774

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Photovoltaics

Centre de Nanosciences & de Nanotechnologies

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C2N News

Reference:
H.-L. Chen and al,
Nature Energy
(2019)

Ultrathin solar cells reach a record of nearly 20% efficiency

Researchers at the *Centre de Nanosciences et de Nanotechnologies* (C2N), in collaboration in particular with researchers at the German Fraunhofer ISE, have succeeded to trap sunlight efficiently in a solar cell thanks to an ultrathin absorbing layer made of 205 nm-thick GaAs on a nanostructured back mirror. With this new architecture, an efficiency of nearly 20% was obtained

Up to now, the laboratory state-of-the-art 20%-efficient solar cells required at least 1 micrometer-thick layers of semiconductor material (GaAs, CdTe or copper indium gallium selenide -CIGS-), or even 40 µm or more in the case of silicon. A significant thickness reduction would enable material savings of scarce materials like Tellerium or Indium and industrial throughput improvements due to shorter deposition times. However, thinning absorber automatically reduces absorption of sunlight and conversion efficiency. A flat mirror at the backside of the cell can help and lead to double-pass absorption, but no more. Previous attempts of light trapping have been greatly limited in performance by the optical and electrical losses.

Researchers of the team led by Stéphane Collin and Andrea Cattoni at the *Centre de Nanosciences et de Nanotechnologies* - C2N (CNRS/University Paris-Saclay), in collaboration in particular with the Fraunhofer ISE, have developed a new strategy to trap light in ultrathin layers made of only 205 nm-thick gallium arsenide, a semiconductor of the III-V family. The guiding idea has been to conceive a nanostructured back mirror to create multiple overlapping resonances in the solar cell, identified as Fabry–Perot and guided-mode resonances. They constrain light to stay longer in the absorber, resulting in efficient optical absorption despite the low quantity of material. Thanks to numerous resonances, absorption is enhanced over a large spectral range that fits the solar spectrum from the visible to the infrared. Controling the fabrication of patterned mirrors at the nanometer scale has been a key aspect of the project. The team used nanoimprint lithography to directly emboss directly a sol-gel derived film of titanium dioxide, an inexpensive, rapid and scalable technique.

Can ultrathin solar cells be further improved? The work published in *Nature Energy* demonstrates that this architecture should enable 25% efficiency in the short term. Even if the limits are still unknown, researchers are convinced that the thickness could be further reduced without efficiency loss, at least by a factor of two. GaAs solar cells are still commercially limited to space application due to their cost. However, researchers are already working on how to extend this concept for large-scale photovoltaics made of CdTe, CIGS or silicon materials.

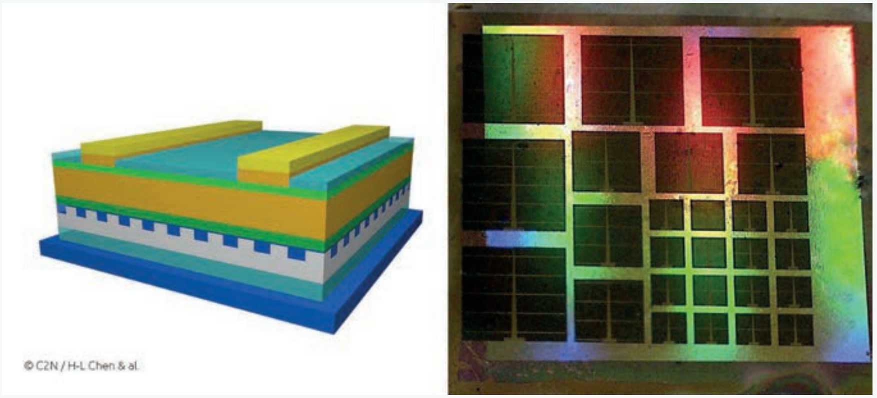

Figure: (left) Sketch of an ultrathin solar cell made of GaAs with a nanostructured back mirror. (right) Photograph of a sample showing the diffraction effect of a nanostructured mirror in air (colored shine) and the absorption enhancement effect in ultrathin solar cells (square black areas). Copyright C2N.

Reference
A 19.9%-efficient ultrathin solar cell based on a 205-nm-thick GaAs absorber and a silver nanostructured back mirror,
H.-L. Chen, A. Cattoni, R. De Lépinau, A. W. Walker, O. Höhn, D. Lackner, G. Siefer, M. Faustini, N. Vandamme, J. Goffard, B. Behaghel, C. Dupuis, N. Bardou, F. Dimroth & S. Collin
Nature Eneergy (2019)
DOI: https://doi.org/10.1038/s41560-019-0434-y

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Physics and Technology of Nanostructures

Centre de Nanosciences & de Nanotechnologies

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April 24, 2019

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News INSIS CNRS

Reference:
K. M. Bastiaans and al,
Nature Physics
(Oct. 2018)

A cryogenic transistor for observing a superconductor

Thanks to its expertise in the realization of cryogenic high electron mobility transistors, a C2N team has enabled a Dutch team to observe at the atomic scale the mechanisms that explain the insulating nature of the surface of a cuprate, a metal-superconductor. The results were published in *Nature Physics*.

Some electronic phenomena in materials can only be observed at very low temperatures, close to absolute zero, in order to minimize thermal noise. For this purpose, researchers can use a low-temperature tunneling microscope (LT-STM), the tip of which operates at less than 4 Kelvin. However, observing certain electron behaviors of the material was still impossible, because of the existing electrical cable between the tip of LT-STM cooled at very low temperature and the amplifier at room temperature (300 Kelvin). Indeed, the capacity of this cable bypasses the signals when they exceed the kilo-hertz. In particular, this was a hurdle for researchers who wanted to study the mechanism by which a cuprate-type superconductor material may have an insulating surface.

A team from the Centre for Nanoscience and Nanotechnology - C2N (CNRS / University Paris-Sud-University Paris-Saclay) has developed a solution using its expertise in the field of realization of cryogenic high electronic mobility transistors "cryoHEMTs". As part of a collaboration with physicists at Leiden University (the Netherlands), a MHz cryogenic amplifier has been optimized and located near the tip of an LT-STM operating at less than 4 Kelvin. Thanks to this device, the Dutch team was able to measure for the first time on the atomic scale the super-Poissonian noise - a characteristic signal of the electrons trapped around impurities - on the surface of the superconducting cuprate. This phenomenon explains the anisotropy of the superconductor, which is insulating in one direction.

The cryoHEMT, produced in the clean rooms of the C2N (one of the 5 Renatech network sites) is the fruit of years of research and development within the C2N. It illustrates the progress of the laboratory that masters the complete fabrication steps: materials, manufacturing processes (molecular beam epitaxy, electron beam lithography, ion beam etching ...), and the characterization of realized circuits. CryoHEMT opens a new horizon for LT-STM, but also for other areas of research at very low temperatures, such as mesoscopic physics, nanoresonators, detectors in astrophysics, or even dark matter detectors[1].

[1] More information: http://phynano.c2n.universite-paris-saclay.fr/en/teams/nanofet/

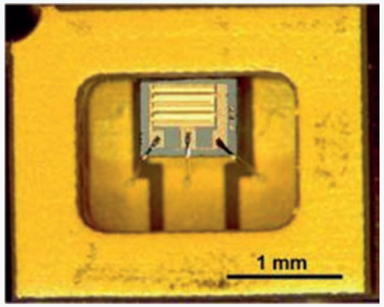

Figure: CryoHEMT realized at C2N © Y. Jin/C2N

Reference
Charge trapping and super-Poissonian noise centres in a cuprate superconductor,
K. M. Bastiaans, D. Cho, T. Benschop, I. Battisti, Y. Huang, M. S. Golden, Q. Dong, Y. Jin, J. Zaanen & M. P. Allan
Nature Physics (2018)
DOI: 10.1038/s41567-018-0300-z

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Centre de Nanosciences & de Nanotechnologies

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May 15, 2019

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C2N News

Reference:
H. Duprez and al,
Physical Review X
(May 2019)

Macroscopic electron quantum coherence in a solid-state circuit

A team of researchers of C2N achieved in an experimental work a coherent propagation of electrons in circuits over macroscopic distances through a novel nano-engineering strategy.

The quantum coherence of electronic quasiparticles underpins many of the emerging transport properties of conductors at small scales. Novel electronic implementations of quantum optics devices are now available with perspectives such as 'flying' qubit manipulations. However, electronic quantum interferences in conductors (quantum coherence length) remained up to now limited to propagation paths shorter than 30µm, independently of the material, geometry and experimental conditions: remarkably similar maximum values were obtained in ballistic semi-conductors, diffusive metals or even 2D materials like graphene.

Using circuit nano-engineering, a team of researchers from the Nanoelectronics Department at C2N have achieved, for the first time, a macroscopic value of the quantum coherence length: 0.25 mm, meaning that it is visible with the naked eye. This result is attained along edge channels that guide electrons in the quantum Hall regime. Normally in this setup, coherence is limited by electron coupling between adjacent channels. To prevent inter-channel collisions, the researchers fabricated a nanostructure that confines electrons to move in small loops within compartments lining the inner channel wall. This confinement forces the inner channels to stay in their ground state, which makes inelastic collisions between electrons impossible. They find that this, combined with outstanding isolation from other decoherence mechanisms, boosts the coherence length by roughly an order of magnitude.

This work extends the possibilities of exploiting the electrons quantum behaviours up to macroscopic length scales and opens new perspectives in quantum electronic optics.

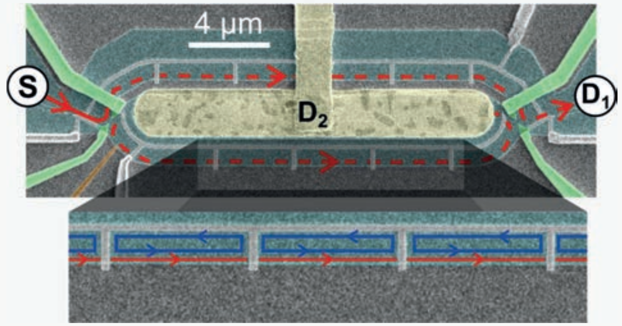

Figure: Colored scanning electron micrograph of the sample: Mach Zehnder interferometer and confinement strategy used to obtain and demonstrate a record electronic coherence length of 0.25 mm. Copyright: C2N.

Reference

Macroscopic electron quantum coherence in a solid-state circuit,
H. Duprez, E. Sivre, A. Anthore, A. Aassime, A. Cavanna, A. Ouerghi, U. Gennser and F. Pierre
Physical Review X (2019)
DOI: https://doi.org/10.1103/PhysRevX.9.021030

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News C2N

Reference:
G. Rodary and al,
Nano Letters
(2019)

Direct mapping of the electronic coupling between two self-assembled quantum dots

Thanks to an advanced technique of scanning tunnelling microscopy and spectroscopy (STM/STS), a team of researchers at C2N was able to observe the electronic coupling of a pair of quantum dots using simultaneous imaging of morphology and electronic density of state.

In the context of quantum technologies, the control of the coupling between confined nanostructures such as cavities, resonators, or quantum dots is essential. This coupling is key to increase the interaction between electrons, phonons or photons, and thus to observe new properties useful for the development of nano-devices. The nature and strength of the interaction are often measured indirectly and on an assembly of dissimilar objects. An important issue today is to be able to measure the interaction between individual and finely characterized nano-objects.

A team of researchers at C2N adopted an innovative point of view by using a specific technique, cross-sectional scanning tunneling microscopy and spectroscopy (STM/STS). They were able to directly map the electronic coupling of individual pairs of self-assembled quantum dots. This work was published in Nano Letters.

The STM/STS equipment allowed, after cliving under ultra-vacuum, to simultaneously image the morphology and the density of electronic coupling of pairs of In(Ga)As/GaAs self-assembled Quantum Dots (QDs) forming Quantum Dots Molecules (QDMs). The researchers highlighted the formation of binding and anti-binding electronic states for these "artificial molecules". Thanks to the support of numerical simulations, they showed the importance of taking into account the exact geometry of the pairs of boxes (i.e. shape, size and distance between boxes), for determining the strength of the coupling.Read the news (in French) on the website of the Université de Sherbrooke.

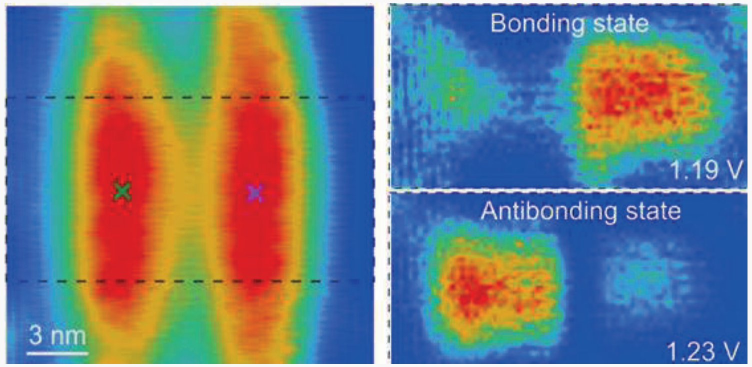
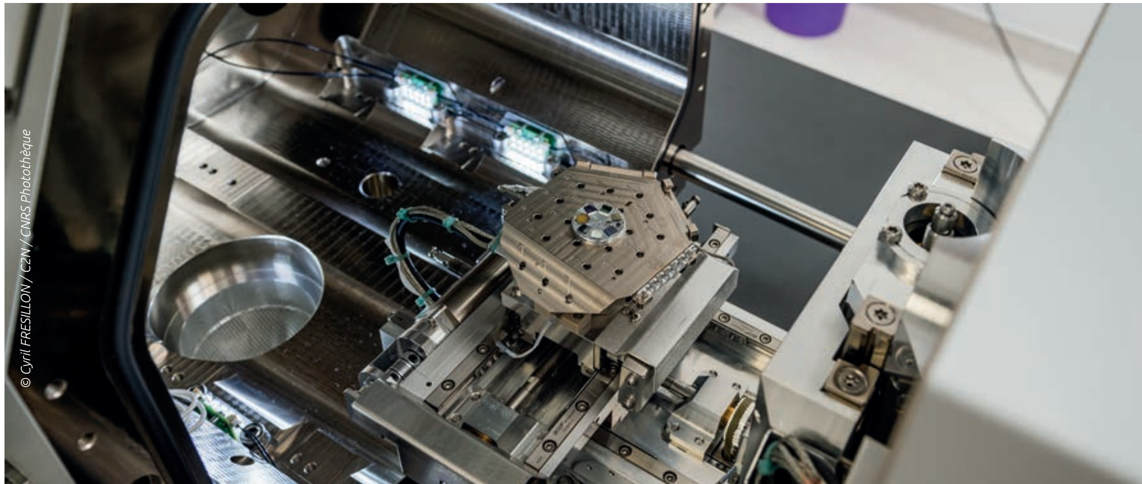


Figure: Left: STM topographic image of a pair of In(Ga)As/GaAs self-assembled Quantum Dots. Right: image of differential conductance (i.e. local electronic state density) of the binding and anti-binding states of the artificial molecule formed from the pair of quantum dots. Crédits: C2N

Reference

Real Space Observation of Electronic Coupling between Self- Assembled Quantum Dots
G. Rodary, L. Bernardi, C. David, B. Fain, A. Lemaître & J.-C. Girard
Nano Letters (2019), 19, 3699–3706
DOI : https://doi.org/10.1021/acs.nanolett.9b00772

Functional Oxides



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C2N News

Reference:
G. Marcaud and al,
Physical Review Materials
(2018)

From the growth to the fabrication and characterisation of oxide-based photonic devices

Thanks to material and photonic scientists, two groups from C2N have demonstrated the potential of Yttria-Stabilized Zirconia (YSZ) oxide for photonic applications.

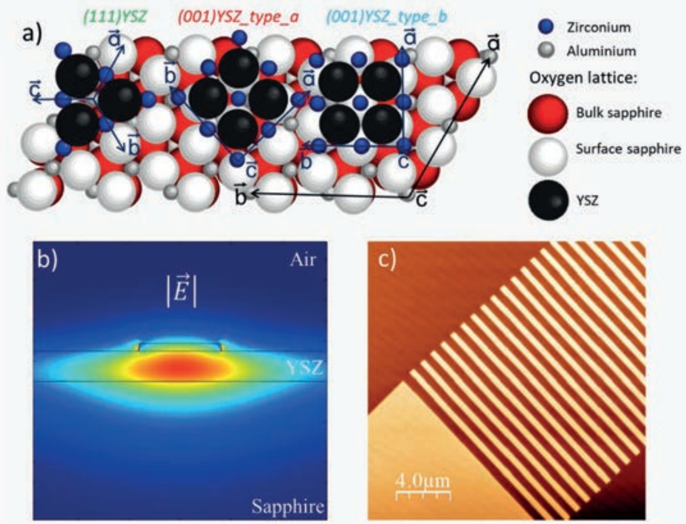
Despite the great progress achieved in silicon photonics the last decade, devices functionalities are still limited by the indirect bandgap and centrosymmetric structure of the semiconductor. As a complementary platform, the hybrid integration of complex oxides has been considered due to the large panel of their properties, interesting for telecommunication, sensors or quantum optics to name few applications.

The lattice matching at the oxides/silicon interface, needed for a high quality of integration, can be ensured with an Yttria-Stabilized Zirconia (YSZ) transition layer. Even if YSZ oxide is well known as an electrolyte for batteries or as a buffer layer in thin film form, it has never been characterized for integrated optics.

Scientists from the *Centre de Nanosciences et de Nanotechnologies* - C2N (CNRS/Univ. Paris-Sud), demonstrated the potential of YSZ for photonic applications. The study and optimization of Pulsed-Laser Deposition (PLD) of YSZ on sapphire substrate allowed the growth of high quality thin film. The structural characterization by X-Ray Diffraction (XRD) and Transmission Electron Microscopy (TEM) revealed that the growth direction is controllable up to a critical thickness of 350 nm. The development of an innovative process of fabrication in cleanroom environment, adapted to the YSZ specifications and to the deposition technique, allowed to build YSZ-based passives photonic devices such as shallow-etched waveguides and grating couplers. Optical characterization in telecom wavelength range (1.3-1.5 µm) revealed propagation losses as low as 2 dB/cm, in the same order of magnitude than the silicon waveguides fabricated in the same facilities. Those results, obtained within the framework of the European project POPSTAR[1], have been published in *Physical Review Material*.

In addition to demonstrate the potential of YSZ in photonic, this study opened the way to the optical nonlinear characterisation of YSZ, whose the first results are very promising. The method and results regarding the growth and fabrication of low-loss YSZ-based waveguides is an important step for the integration of complex oxides in photonic.

[1] *H2020 European project ERC POPSTAR: Low power consumption silicon optoelectronics based on strain and refractive index engineering*



Figures: Crystalline orientation of YSZ on sapphire and YSZ-based passives photonic devices. a) The structural characterization revealed the high quality of YSZ thin films and the three grains orientations with either (111) or (001) growth direction on sapphire substrate. Optimization of Pulsed-Laser Deposition (PLD) allowed to control the growth direction, keeping the crystalline quality, below a critical thickness of 350 nm. b) Optical mode simulation at λ=1550 nm of YSZ-based waveguide (nysz=2.15) on sapphire (nsaph=1.74). The single-mode waveguides allowed the confinement and propagation of quasi-TE mode with an electric field direction in the thin film plane. c) AFM picture of a passive photonic structure made in YSZ thin film: a grating coupler and a taper. © C2N

Reference

High-quality crystalline yttria-stabilized-zirconia thin layer for photonic applications,
G. Marcaud, S. Matzen, C. Alonso-Ramos, X. Le Roux, M. Berciano, T. Maroutian, G. Agnus, P. Aubert, L. Largeau, V. Pillard, S. Serna, D. Benedikovic, C. Pendenque, E. Cassan, D. Marris-Morini, P. Lecoeur and L. Vivien
Physical Review Materials 2, 035202 (2018)
DOI: https://doi.org/10.1103/PhysRevMaterials.2.035202

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C2N News

Reference:
S. Matzen and al,
Advanced Electronic Materials
(2019)

Controlling with light the amplitude and the direction of the deformation of a material

Thanks to the integration and characterization of ferroelectric thin films into capacitive micro-devices, a team of researchers at C2N has shown that it is possible to control their photostrictive response with a sub-nanosecond time resolution by playing on the internal electric field.

The generation of deformations under illumination in ferroelectric materials, or photostriction, is known to be a complex mechanism combining the photovoltaic effect (generation of electron-hole carriers under optical illumination) and the inverse piezoelectric-effect (mechanical deformation induced by an electric field). This relatively unexplored phenomenon is currently attracting increasing interest with the aim to develop and integrate new functionalities into devices. Until now, research has mainly remained focused on fundamental studies of bulk materials, making their technological integration difficult. Some recent studies on thin films have revealed significant strain rates (of the order of 10^{-3}) at very fast time scales (around 100 picoseconds). Nevertheless, in these investigations the thin films remained with their initial ferroelectric polarization, without any possibility of ex situ control of the photoinduced deformations.

Thanks to the C2N cleanroom Technology facility, researchers at C2N were able to integrate and characterize ferroelectric thin films of $Pb(Zr,Ti)O_3$ (PZT) into microdevices. The photostrictive response could be studied, and controlled, in operando by applying a voltage to modify the ferroelectric polarization state. More precisely, time-resolved X-ray diffraction measurements were carried out at the APS synchrotron (Argonne, USA)[1]. This made it possible to study the photoinduced changes of the PZT lattice parameter following a UV pulse with a time resolution of 100 picoseconds. Researchers at C2N have shown that it is possible to control both the direction (contraction or elongation) and the amplitude of photoinduced deformation at a sub-nanosecond time resolution by playing on the photoinduced variation of the internal electric field. Thus, photostriction can generate both elongations and contractions by controlling the state of polarization of the ferroelectric material. In addition, two distinct remanent photostrictive states could be achieved. This work was published in the journal *Advanced Electronic Materials*.

These results provide fundamental information on the light-matter interaction in ferroelectrics and promise new paths for the engineering of multifunctional materials. In particular, the optical control of their properties could be exploited in novel memory type devices, or more generally in all the systems where a transient electric field or a transient strain allows controlling materials' functionalities.

[1] *In the framework of the collaboration with the International Research Laboratory Nanoelectronics*

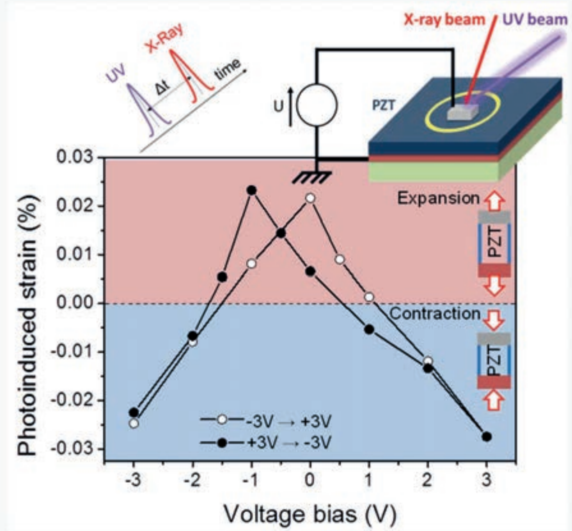

Figure: (top) Sketch of pump-probe experiments allowing to measure by X-ray diffraction the lattice parameter, following a UV pulse, of a ferroelectric thin film of PZT integrated between two electrodes. (bottom) Photoinduced deformation 2.5 nanoseconds after the UV pulse, depending on the applied voltage, showing a hysteresis phenomenon and the control of the amplitude and the sign of the deformation, with two distinct photostrictive responses when voltage is at zero. © C2N / S. Matzen & al.

Reference

Tuning Ultrafast Photoinduced Strain in Ferroelectric-Based Devices,
S. Matzen, L. Guillemot, T. Maroutian, S. K. K. Patel, H. Wen, A. D. DiChiara, G. Agnus, O. G. Shpyrko, E. E. Fullerton, D. Ravelosona, P. Lecoeur and R. Kukreja
Advanced Electronic Materials (2019), 1800709
DOI: https://doi.org/10.1002/aelm.201800709

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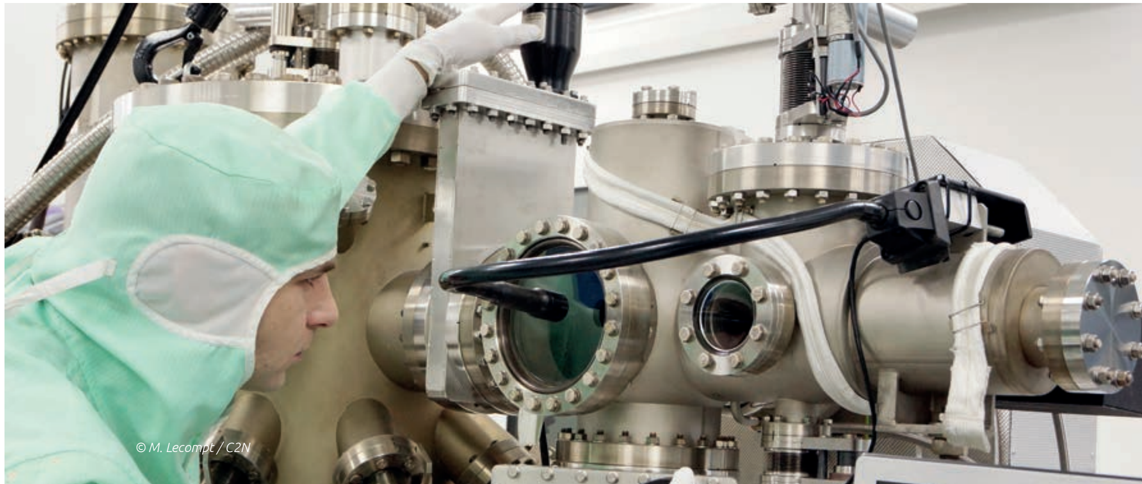
- Department of Materials Science and Engineering, University of California Davis, USA

Elaboration and Physics of Epitaxial Structures


© M. Lecompt / C2N

Centre de Nanosciences & de Nanotechnologies

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November 29, 2019

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News INSIS CNRS

Reference:
Y. A. Bioud and al,
Nature Communications
(2019)

Nanoporous germanium for cheaper multi-junction solar cells

Despite their excellent energy performance, some solar panels are still too expensive to be used widely. Researchers from the *Laboratoire Nanotechnologies et Nanosystèmes* (LN2), the *Centre de Nanosciences et de Nanotechnologies* (C2N) and the University of Warwick (UK) have managed to reduce the costs of multi-junction solar cells thanks to the use of nanoporous germanium. This work, that enables to reduce the presence of defects on different crystalline substrates, was published in *Nature Communications*.

Multi-junction solar cells offer excellent performance, but at a cost that is still too high. The incident light must be concentrated by lenses to make the system more profitable, which is not enough yet to compete with conventional solar cells. Researchers from the *Laboratoire nanotechnologies et nanosystèmes* - LN2 (international joint research unit* between France and Canada), the *Centre de nanosciences et de nanotechnologies*** - C2N (CNRS/Université Paris-Saclay) and the University of Warwick in the United-Kingdom managed to lower the price thanks to the use of nanoporous germanium.

Solar cells need a crystalline substrate, representing about a third of the total cost. It usually means a 150 micron layer of germanium for multi-junction cells, which could be replaced by silicon that is much cheaper. However, the contact between silicon, germanium and the cell causes the appearance of defects and leads to a decrease of the energy yields. To solve this problem, the researchers inserted a layer of only 2 microns of nanoporous germanium between the silicon and the rest of the cell. Some defects still appear, but they are totally erased with a process of electrochemical etching. Costs are halved, while the performance is improved. This technique can also be used to integrate III-V semiconductors, such as gallium arsenide, which are interesting for many applications in electronics. The team is now looking for new opportunities and collaborations.

- Read the news (in French) on the website of the Université de Sherbrooke.

** Between CNRS, Université de Sherbrooke, Université de Lyon – Ecole Centrale de Lyon, INSA and CPE/Université Grenoble Alpes*

*** Most of the structural characterization studies were performed with the Transmission Electron Microscope (TEM) Titan Themis at C2N (Material Analysis Platform – Materials Department). See Figure.*

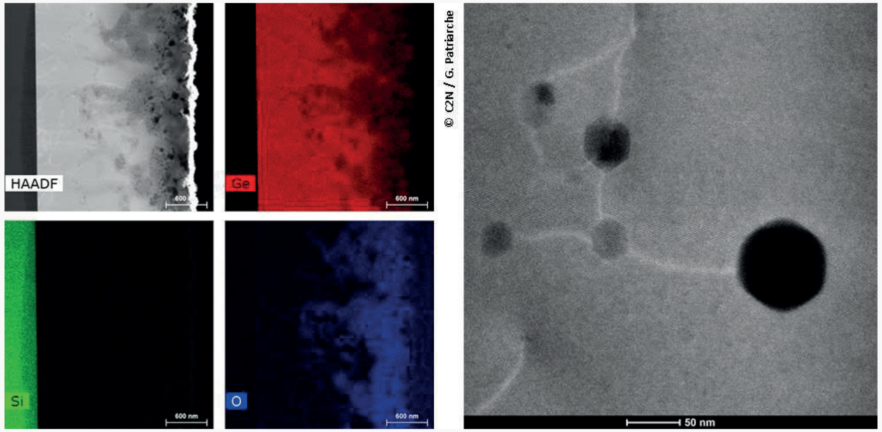

Figure: (left) Elemental chemical mapping by STEM-EDX of a nano-porous germanium layer. (right) Threading dislocations present in the epitaxial layer of germanium anchored by the nanopores - STEM image in dark field (HAADF). © C2N / G. Patriarche

Reference

Uprooting defects to enable high-performance III–V optoelectronic devices on silicon,
Y. A. Bioud, A. Boucherif, M. Myronov, A. Soltani, G. Patriarche, N. Braidy, M. Jellite, D. Drouin & R. Arès
Nature Communications - volume 10, article number: 4322 (2019)
https://www.nature.com/articles/s41467-019-12353-9

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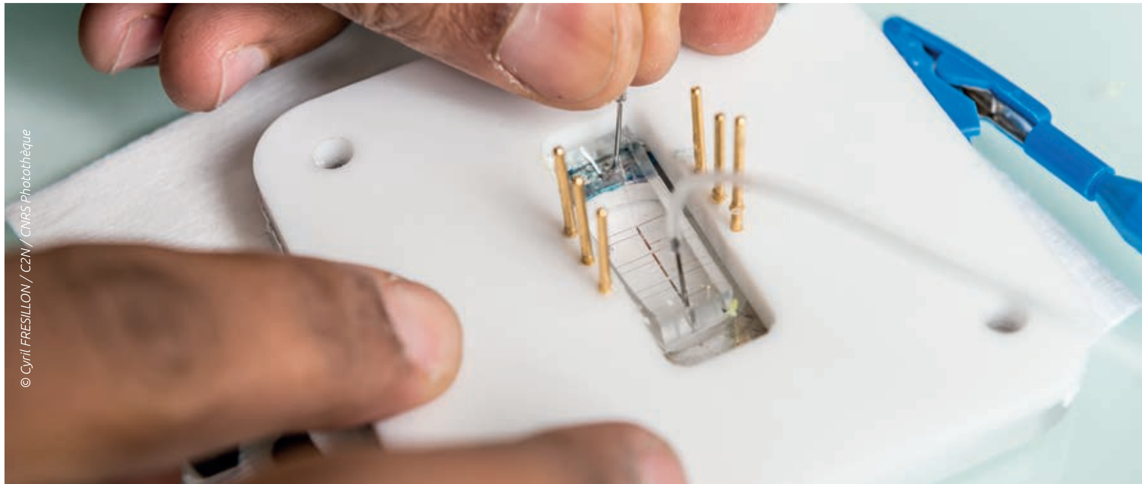
Nanotechnology and microfluidic devices



Centre de Nanosciences & de Nanotechnologies

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CNRS *La Lettre Innovation*

A lab-on-a-chip for the ultrasensitive detection of biomarkers

A team of researchers at the *Centre de Nanosciences et de Nanotechnologies* has developed an innovative microfluidic technology for the analysis of microRNA. The device is designed for the rapid detection of biomarkers in biological fluids and opens the door to early diagnosis without the need to remove tissue samples.

The liquid biopsy, which could detect early cancer by simple blood or urine analyse, without extraction of tissue samples, is still in the research stage. It involves the development of ultra-sensitive detection techniques for biomarkers (DNA or RNA found in the blood, for example). The lab-on-a-chip device developed by a team of the *Centre de Nanosciences et de Nanotechnologies* paves the way for rapid and ultra-sensitive diagnostics1. Based on microfluidic technology, it is able to carry out the capture, the release and the detection of a micro-RNA specific for liver cancer. The system has been patented2.

Micro-RNAs (miRNAs) circulating in the blood represent some very promising biomarkers for the early detection of various pathologies: cardiovascular diseases, haemorrhagic shocks, cancerous lesions... Currently, the analysis of miRNAs is generally separated into three stages: the extraction of the total RNAs, including miRNAs, from plasma or serum ; the reverse transcription (RT) of RNAs into complementary DNAs ; and their amplification by PCR (polymerase chain reaction). The major drawbacks of this technique are the duration of the analysis -6 hours on average- and the potential errors during the amplification and detection phase.

Researchers at the *Centre de Nanosciences et Nanotechnologies* - C2N (CNRS/Univ. Paris-Saclay) propose a very different approach called the HDE (Hyperthermia and Electrochemical Detection) technology. It is based on the over-concentration of RNA strands in a microfluidic device. Magnetic nanoparticles pre-equipped with DNA probes ("locks") are used for the specific capture of target micro-RNAs ("keys"). Magnetic hyperthermia is then used to heat locally and allow the release of RNA strands. Finally, the ultimate detection is performed by electrochemistry on functionalized microelectrode probes for the new dropping of target microRNAs. The integration of these integrated operations in a microfluidic device offers multiple advantages: capture of different types of miRNA in the same sample, the possibility to release without overall elevation of the temperature, the possibility to decrease the volume of the sample needed for the analysis (around a nanoliter), plus the miniaturization and automation of the system (see picture).

The device has demonstrated its validity in the laboratory, by detecting one of the specific miRNAs of liver cancer. All the steps were carried out in less than 3 hours, with an extremely low detection threshold (10-18 mol / L), better than those using PCR-type protocols. The C2N team is now developing an integrated prototype, as part of a project co-financed by two programs: CNRS (AAP Prématuration 2018) and Labex NanoSaclay (AAP Valorisation 2018). «The objective is to have a working prototype at the end of 2019, then to co-develop an industrial prototype in 2020 with a company», says Jean Gamby3, researcher at Centre de Nanosciences et de Nanotechnologies.

The new ultra-sensitive instrument could be used in prevention (early detection), but also for biological analyses in emergency services, or even directly in the field. The same method could be applied to the detection of other biomarkers, and thus to the prevention of other pathologies.

[1] The device was developed in collaboration with:
The team « Colloïdes Inorganiques du laboratoire PHysico-chimie des Electrolytes et Nanosystèmes InterfaciauX » – PHENIX (CNRS, Sorbonne Université)
The « Unité des Technologies Chimiques et Biologiques pour la Santé » – UTCBS (CNRS, Chimie ParisTech, Université Paris Descartes)

[2] Patent 1759346 in co-ownership CNRS, INSERM, Sorbonne Université and Paris Descartes filed on the 5 October 2017. Procédé de détection de molécules d'acides nucléiques par hyperthermie magnétique et ensemble permettant une telle détection. M.-C. Horny, J. M Siaugue, M. Lazerges, V. Dupuis, J. Gamby, Declaration of invention CNRS n°633-01, May 2017, FR demande 1759346, 5 octobre 2017. Extension 5 octobre 2018, PCT/ EP2018/0772080.

[3] Supported by Valoritech "Créateur de valeurs" for the strategy

Micro and Nano-Technologies Innovation

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Centre de Nanosciences & de Nanotechnologies

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LE GRATIET Luc
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CNRS *La Lettre Innovation*

Measurement standards at the nanoscale for AFM and SEM microscopes

The *Laboratoire National de métrologie et d'Essais* and the *Centre de Nanosciences et de Nanotechnologies*[1] co-developed a nanoscale transfer standard prototype that calibrates atomic force and scanning electron microscopes. The standard is based on the meter of the International System of Units and thus provides an essential link for reliable dimensional measurements.

Nanotechnologies make it possible to provide materials with new mechanical, electrical or optical properties. For the many research and industrial laboratories active in this field it is necessary to correlate properties that appear only at the nanoscale with reliable dimensional measurements. It is therefore essential to link the measurements made at the nanometer scale with the definition of the meter in the International System of Units (SI).

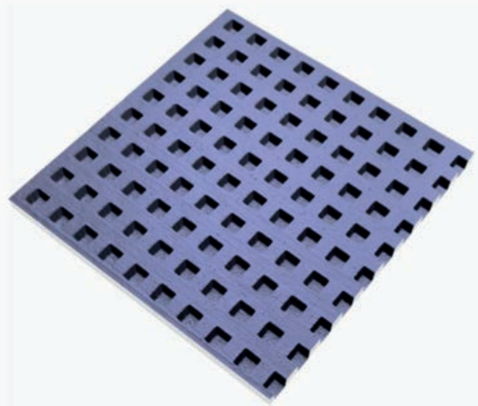
To date, users of Atomic Force Microscopes (AFMs) and Scanning Electron Microscopes (SEMs), which measure the dimensions of nanostructures (surface roughness, thickness of thin layers, depth of nanometric patterns, etc.), have no standard to calibrate their instruments. Calibrations are done using periodic gratings of micrometric patterns, leading to high levels of uncertainty on the measurements made thereafter. To fill this gap the Laboratoire National de métrologie et d'Essais and the le Centre de Nanosciences et de Nanotechnologies1 have jointly developed a nanoscale measurement transfer standard2.

To realize a transfer standard, a reference measurement is first required. Several years ago the *Laboratoire National de métrologie et d'Essais* developed such a standard using an AFM. The position of the AFM tip relative to the sample is determined very precisely by laser interferometers whose wavelength is calibrated with respect to the frequency stabilized reference laser used for the definition of the meter. This 'metrological' AFM thus makes it possible to calibrate the dimensional characteristics of transfer standards (in particular structures having periodic patterns and controlled operating steps) with uncertainties in the order of nanometer (nm).

The *Centre de Nanosciences et de Nanotechnologies* have now implemented the nanofabrication technologies of the standard. This consists of a 2D periodic grating, etched on a 250 µm x 250 µm surface in the center of a 10 mm x 5 mm silicon substrate.

The grating is first patterned by electron beam lithography (direct writing by an electron beam of a few nanometers in diameter) in a polymer, which serves as a mask during the transfer into silicon via dry etching. The nominal grating pitch is 900 nm (along the X and Y axes) and the nominal height 60 nm. The uncertainties amount to ± 2 nm for the grid pitch and ± 1 nm for the step height.

From this P900H603 transfer standard it is hence possible to extract an average value of the grating pitch, allowing a standard calibration of the instruments along the X and Y axes (AFM and SEM), and a value of the average step height for the Z-axis calibration (AFM). The determination of these characteristic dimensions by means of the LNE 'metrological' AFM will enable certified standard dimensions and their corresponding uncertainties (± 2 nm for the grid pitch and ± 1 nm for the step height).



[1] C2N (CNRS/Université Paris-Sud)

[2] A transfer standard makes it possible to link measurements made with the primary instrument (here the 'metrological' AFM) to a conventional laboratory instrument.

[3] The development of this transfer standard is a continuation of the actions of the Club nanoMétrologie, created in 2011, which is the subject of a partnership agreement between LNE and the CNRS represented by UPS C'Nano. The club now has nearly 400 members, 30% of whom are industrial companies. Among its actions, the club leads several working groups around nanometrology, one of which focuses on the traceability of measurements at the nanoscale and in particular the definition of requirements for measurement standards of transfer and reference materials.

Awards & Distinctions* in 2019

**the list is not exhaustive but highlights the most significative distinctions received in 2019 by C2N members.*

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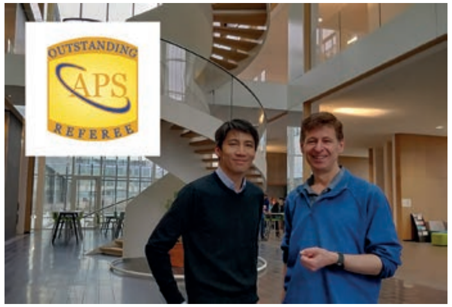

Joo-Von Kim, CNRS researcher at C2N is listed among the 2019 Outstanding Referees of the American Physical Society (APS).

The Outstanding Referee program was instituted to recognize scientists who have been exceptionally helpful in assessing manuscripts for publication in the APS journals. The honorees are selected based on the quality, number, and timeliness of their reports, without regard for membership in the APS, country of origin, or field of research.

Ulf Gennser, CNRS senior researcher at C2N, was honored with the same recognition in 2014.

Loïc Lanco, Associate Professor at Université de Paris and researcher at C2N, was nominated junior member of the *Institut universitaire de France* (IUF) for five years.

The research activity of Loïc Lanco at C2N focuses on light-matter interfacing at the single-photon level, using semiconductor quantum dot / cavity structures. He headed the Physics BSc of University Paris Diderot (Université de Paris) from 2014 to 2018.

Delphine Marris-Morini, Professeur at University Paris-Saclay and researcher at C2N, received the same recognition in 2013 for her work in the field of Optoelectronics – silicon photonics.

The startup Spin-Ion Technologies, co-founded by Dafiné Ravelosona, CNRS Senior Researcher at C2N, was awarded with one of the 10 Grands Prix «i-LAB 2019» from the French Minister of Higher Education and Research.

The start-up provides an answer to the challenge of the digital transformation. It has developped an innovative process to be integrated on the production lines of MRAMs, a new memory with the potential to replace all existing memories that reach their limits.

The solution is based on the use of a specific ion beam to treat ultra-thin magnetic films in order to improve their structural properties. The performance of MRAMs, which use these materials, are thus increased. Spin-Ion Technologies has initiated partnerships with several global industry leaders in the development of MRAMs and related equipments.

In 2018, the startup Quandela, another spin-off of C2N was awarded a Grand Prix i-LAB.

INSTITUT DE FRANCE
Académie des sciences

Jacqueline Bloch, CNRS Senior Researcher at C2N, was awarded the *prix Ampère de l'Électricité de France* 2019. The *Académie des sciences* honored her during a solemn presentation of her prize under the Coupole of the Institut de France in October.

In December, she was elected member of the *Académie des sciences*, in the physics section!

Jacqueline Bloch's work is pioneering in the field of cavity polaritons in semiconductors. Early in her career, she became interested in the ultimate confinement of electrons and light in nanostructures, in order to exalt and control light-matter interaction. Thanks to her experimental breakthroughs, together with her deep understanding of a subtle subject, she is now a world leader in the field of polariton quantum fluids. Her research on this system added an invaluable contribution to a broad field of physics, that ranges from liquid helium to ultra-cold quantum gas.

The impact of her work is evidenced not only by the high number of citations of her publications, but also by the many requests she received for collaboration coming from experimenters and theorists, in France and abroad (Spain, Italy, Israel, Germany, United Kingdom ...).

She actively participates to the management of research, at the local level in her laboratory, at the national level at the *comité national du CNRS*, at the international level in the ERC panels. She is renowned for the clarity of her lectures, and students can benefit from her teaching skills, especially at the *Institut d'Optique* and the *Ecole Polytechnique*.

OSA The Optical Society

EOS European Optical Society

Ariel Levenson, CNRS Senior Researcher at C2N, was elected **EOS Fellow 2017/2018**

Laurent Vivien, CNRS Senior Researcher at C2N, was elected **OSA Fellow 2020**

erc
European Research Council
Established by the European Commission

Rebeca Ribeiro-Palau, CNRS researcher at C2N, is laureate of an ERC Starting Grants 2019 for her project Twistronics (Probing topological valley currents by layer alignment in van der Waals heterostructures).

Rebeca is an experimental condensed matter physicist. She obtained her PhD at the Universite Paul Sabatier in Toulouse. She did a postdoc at the French National Metrology lab (LNE) and then at Columbia University. In November 2017, she got tenured CNRS researcher at C2N to investigate the generation and control of different topological orders in van der Waals heterostructures.

For its 39th edition, the *Journées Nationales d'Optique Guidée* took place at C2N in July. The event was co-organized with the French Society of Optics (SFO).

The Organizing Committee was composed of the SFO, Béatrice Dagens (C2N), Frédéric Grillot (Telécom Paris Tech) and Pierre Lecoy (Centrale Supélec).

The annual meeting of the LabEx NanoSaclay (*Laboratoire d'Excellence interdisciplinaire en Nanosciences et Nanotechnologies de Paris-Saclay*) took place at the C2N in September.

The LabEx gathers 30 laboratories, 500 researchers and a 2900m² Technology Facility (cleanroom) in Paris-Saclay area.

The C2N and the New York University (NYU) Center for Quantum Phenomena organized a French-US symposium on nanelectronics in September, in Paris (NYU Paris site) and Palaiseau (C2N).

The symposium marked the opening of the new C2N laboratory and celebrated the joint lab in Nanoelectronics. Around 20 French and American speakers covered research topics in spintronics, superconducting devices, oxide heterostructures and neuromorphic computing.

The C2N organized the Micro- and Nanophotonics Days 2019 in November. This 2-days scientific workshop covered a wide range of thematics in photonics.

It aimed at establishing an international synergy around the C2N, that hosts one of the largest European research department in photonics. The workshop was organized around Keynote talks given by internationally renowned speakers who introduced their research topic and presented their latest advances.

The workshop "Quantum and neuromorphic technologies meet" was hosted at C2N on November 27th, 2019. It was organized by Damien Querlioz (C2N) and Danijela Marković (UMPhy CNRS/Thalès), supported by 3 GDR: SoC2, BioComp and IQFA.

The goal was to give opportunity to the actors of these two, until now independant fields, to meet and exchange ideas.

Events at C2N in 2019

30 PhD Defended:
Claire ABADIE, Frédéric BANVILLE, Pierre BONNET, Petru BORDA, Laurent BOULLEY, Vincent BRAC DE LA PERRIERE, Elena DURAN VALDEIGLESIAS, Anas ELBAZ, Ludivine EMERIC, Valentin GOBLOT, Antu GORTARI, Sylvain GUERBER, Paul HILAIRE, Arnaud JOLLIVET, Qiankun LIU, Amadeo MICHAUD, Sokhna Mery NGOM, Dorian OSER, Alisier PARIS, Daniel PELATI, Alexandra PETRETO, Emile SIVRE, Etienne THIEBAUT, Pierre-Baptiste VIGNERON, Gefel WANG, Jérôme WILLIAME, Martin ZAHRADNIK, Boyu ZHANG, Jianhao ZHANG, Rui ZHU

2 HdR Defended
Liza HERRERA DIEZ, Charles RENARD

24 C2N General Seminars
Carlos Alonso-Ramos (C2N)
Sylvain Ravets (C2N)
Kees van der Beek (C2N)
Frederic Pierre (C2N)
Michel Thiebaut (ICM, Paris)
Galo Soler Illia (INS-UNSAM, Buenos Aires)
Konstantinos Pantzas (C2N)
Loic Lanco (C2N)
Hadrien Duprez (C2N)
Pierre Francois Cohadon (LKB, Paris)
Amaury Delamarre (C2N)
Eleni Diamanti (UPMC, Paris)
Federico Panciera (C2N)
Rebeca Ribeiro (C2N)
Herve Aubin (C2N)
Damien Querlioz (C2N)
Remy Braive (C2N)
Laura Thevenard (INSP, Paris)
Francesca Chiodi (C2N)
David Garcia Fernandez (ICN2, Barcelona)
Anne-Marie Haghiri (C2N)
Philippe Lalanne (IOGS, Bordeaux)
Xavier Marie (INSA Toulouse)
Liza Herrera Diez (C2N)

2 Colloquia
Alain Aspect (LCF, IOGS/CNRS)
CNRS Gold Medal 2005

William Phillips (NIST/Univ. of Maryland)
Nobel Prize in Physics 1997

More than 13 workshops, symposiums and summer schools organized at C2N !

C2N
Centre de Nanosciences & de Nanotechnologies

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January 2020