New opportunities based on large-scale 300 mm silicon photonic technologies

The aim of the Nanoelec/Photonic Sensors program is to produce a complete range of solutions designed to facilitate the adoption of photonics on silicon by new applications requiring complex detection functions, such as 3D detection in mobile phones, self-driving vehicles, or biochemical detection for health care purposes and environmental monitoring.

STÉPHANIE GAUGIRAN (CEA), HEAD OF THE NEW PHOTONIC APPLICATIONS SECTION AT CEA-LETI & DIRECTOR OF THE NANOELEC/PHOTONIC SENSORS PROGRAM

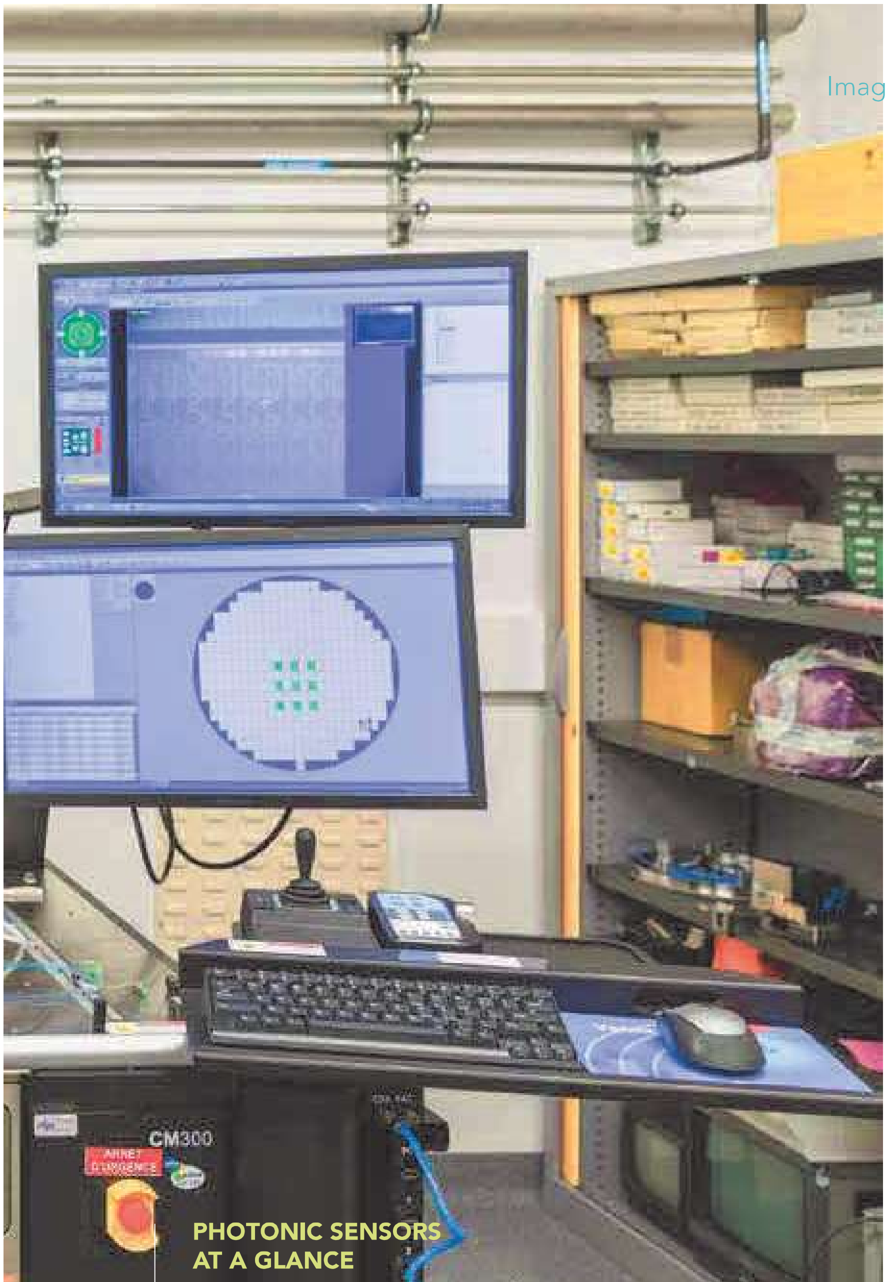
The main key technological challenges for this type of sensor are measurement precision, miniaturization, data processing and transfer and compatibility with mass production. The unique properties and performance of integrated photonics are essential in meeting these challenges.

In 2024, a first demonstration of ethanol detection without substrate functionalization was performed using a two-wavelength Mach Zehnder interferometer. Initial results are highly promising.

Our teams performed a study of a physical phenomenon limiting long-range LIDAR applications, which require high power levels: the non-linear two-photon absorption (TPA) phenomenon. The process was transferred to STMicroelectronics at the end of the year.
Work on very low loss SiN guides improved the platform's results and its performance is now world-class.

Finally, the year was marked by the production of the 300mm laser batch and the first structures were successfully tested. •

AGENDA



PHOTONIC SENSORS AT A GLANCE

→ **Vision**
New sensor opportunities based on large-scale 300mm silicon photonic industrial technologies

→ **Ambition**
Provide the Nanoelec partners with a complete chain of solutions – from EDA to mass production – designed to facilitate the adoption of photonics on silicon by new applications requiring complex detection functions such as 3D detection in mobile phones, autonomous vehicles, or biochemical detection for health care and environmental surveillance

→ **Mission**
Our main technological challenges for such sensors are measurement precision, miniaturization, data processing and transfer, and also compatibility with mass production. The unique properties and performance of integrated photonics are essential in being able to meet these demands and these challenges

→ **Partners**
Almae, CEA, CNRS, Siemens EDA, STMicroelectronics

AGENDA

MZI based ethanol detection

CEA is developing an application measuring the ethanol concentration using an MZI without functionalization on the STMicroelectronics platform, within Nanoelec.

Measurements down to 0.2% alcohol concentration in water were achieved, with a detection limit evaluated at 0.025%. A CMOS photonics on silicon interferometer allows measurement of very small quantities of liquid. The application could be of interest to the agri-food industry and the health care sector.

Millimeter-length antennas for optical-phased arrays

Improving the scanning accuracy.

A team gathering scientist from CEA, STMicroelectronics, C2N (CNRS & Université Paris-Saclay) studied the behavior of mm-long BIC-effect and dual-layer antennas for silicon photonics based optical phased-arrays (OPAs).

"The designed and fabricated antennas are simulated and characterized in terms of divergence and directivity in order to achieve precise scanning of the environment," underlines Louise-Eugénie Bataille (STMicroelectronics) as first author of the paper awarded as the "IEEE Silicon Photonics Conference 2024 - Best Student Paper"[1].

In further work, BIC-effect and dual-layer Si-SiN SWGAs will be integrated in active OPA with carrier depletion phase control. The apodisation of the gratings period is foreseen for next designs. *"This should confirm the potential of scanning the environment with mm long SWGAS in order to expand the OPA to several hundreds of channels and improve the scanning accuracy of OPA-based sensing applications,"* concludes Louise-Eugénie Bataille.

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Laser integration

Silicon photonics technology and devices for machine learning.

Benoît Charbonnier & al. (CEA-Leti) demonstrated how silicon photonics for AI is suited to use cases where high computational speed is required.
"CEA Leti's SiPho platform offers state of the art performance for photonic accelerators," underlines Benoit Charbonnier. *"In the future, wafer scale (spiking) laser integration could be a good candidate to support full analog neural networks."* These results were presented at Photonic West (January 2024, San Francisco, USA), the conference attracting more than 24,000 attendees from 70 countries.[2]

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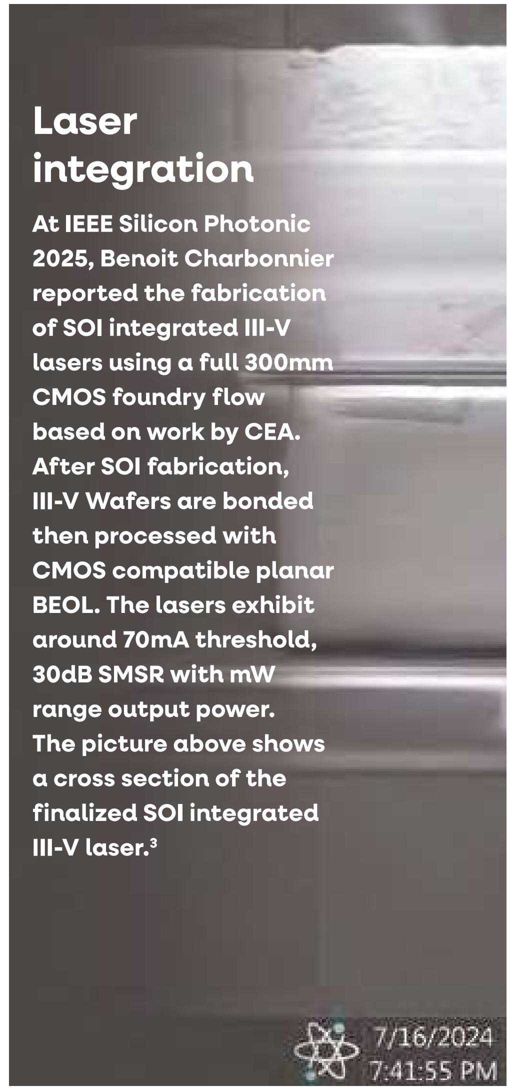


Laser integration

At IEEE Silicon Photonic 2025, Benoit Charbonnier reported the fabrication of SOI integrated III-V lasers using a full 300mm CMOS foundry flow based on work by CEA. After SOI fabrication, III-V Wafers are bonded then processed with CMOS compatible planar BEOL. The lasers exhibit around 70mA threshold, 30dB SMSR with mW range output power. The picture above shows a cross section of the finalized SOI integrated III-V laser.[3]

1. Silicon Photonics Conference (SiPhotonics, April 2024, Tokyo, Japan).

2. Charbonnier, B., Malhouitre, S., Ramez, V., Bellemin-Comte, A., Ribaud, K., Coppola, G., Faure, T., Dafonseca, J., Thibon, T., & Jany, C. (2024, janvier 30). Silicon photonics technology and devices for machine learning. Photonic West.

3. Charbonnier, B., Bellemin-Comte, A., Adelmini, L., Mathieu, V., Stigliani, M., Castan, C., Philip, P.-E., Hebras, D., Hartmann, J.-M., Ribaud, K., Szelag, B., & Hassan, K. (2025). 300mm IIIV on SOI laser integration process, fabrication and prototyping. 2025 IEEE Silicon Photonics Conference (SiPhotonics), 1-2. https://doi.org/10.1109/SiPhotonics64386.2025.10985732

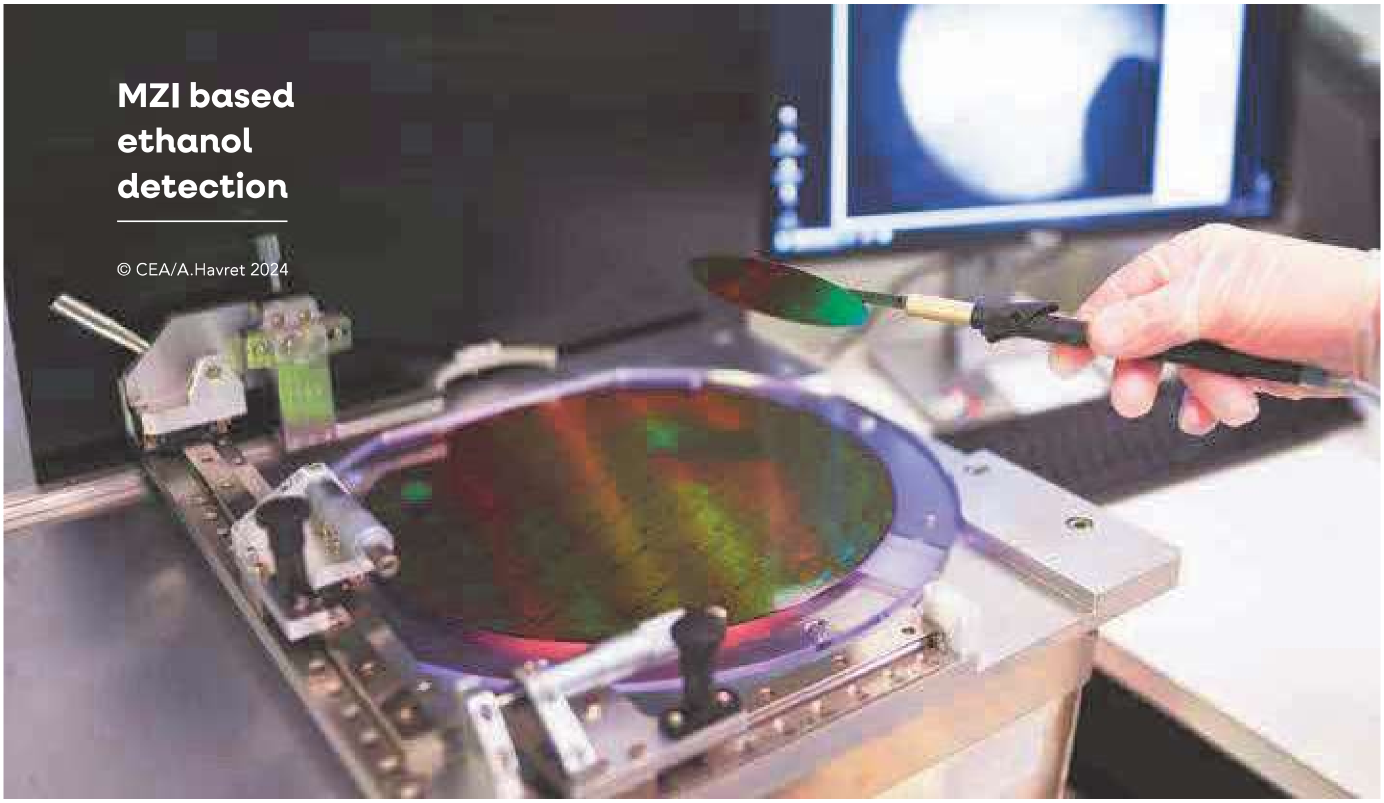
GaAs for photonic and optoelectronic devices

III-V monolithic integration on silicon compatible with CMOS processes.

The integration of III-V compound semiconductors on a silicon platform has emerged as a transformative approach to enhancing the performance and functionality of photonic and optoelectronic devices.

A team from CNRS/LTM, CEA, Grenoble INP-UGA and UGA associated within Nanoelec presented recent achievements, challenges, and future prospects of GaAs monolithic integration on silicon with specific focus on the development of near-infrared (NIR) emitters and photodetectors. *"We address the challenges associated with III-V monolithic integration on silicon and its compatibility with CMOS processes. These challenges include lattice mismatches, thermal management, and process scalability,"* explains Thierry Baron (CNRS/LTM) as first author of the paper presented at Smart Photonic and Optoelectronic Integrated Circuits 2024 (January 2024, San Francisco, California).

The latest results were obtained on near-infrared resonant cavity enhanced photodetector and light emitting devices integrated onto a nominal Si(001) substrate. *"The device structures have been optimized by incorporating active regions based on InGaAs/GaAsP strained-layer super-lattices and GaAs/AlGaAs distributed Bragg Reflectors. We also show an alternative solution for fabricating low-threshold emitters based on III-As membranes and lateral injection devices,"* Thierry Baron says.



MZI based ethanol detection

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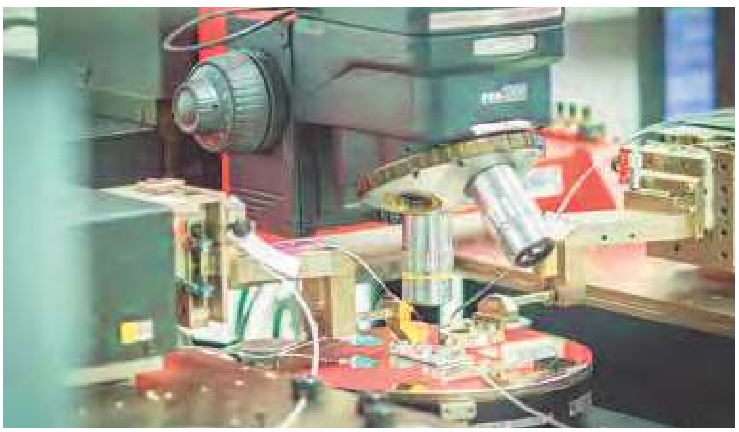

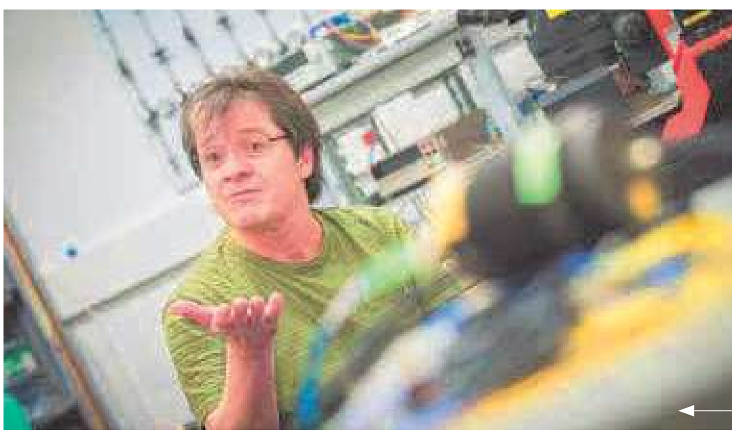

PIERRE LABEYE (CEA-LETI), DEVELOPING A SENSOR FOR ALCOHOL DOSE TITRATION

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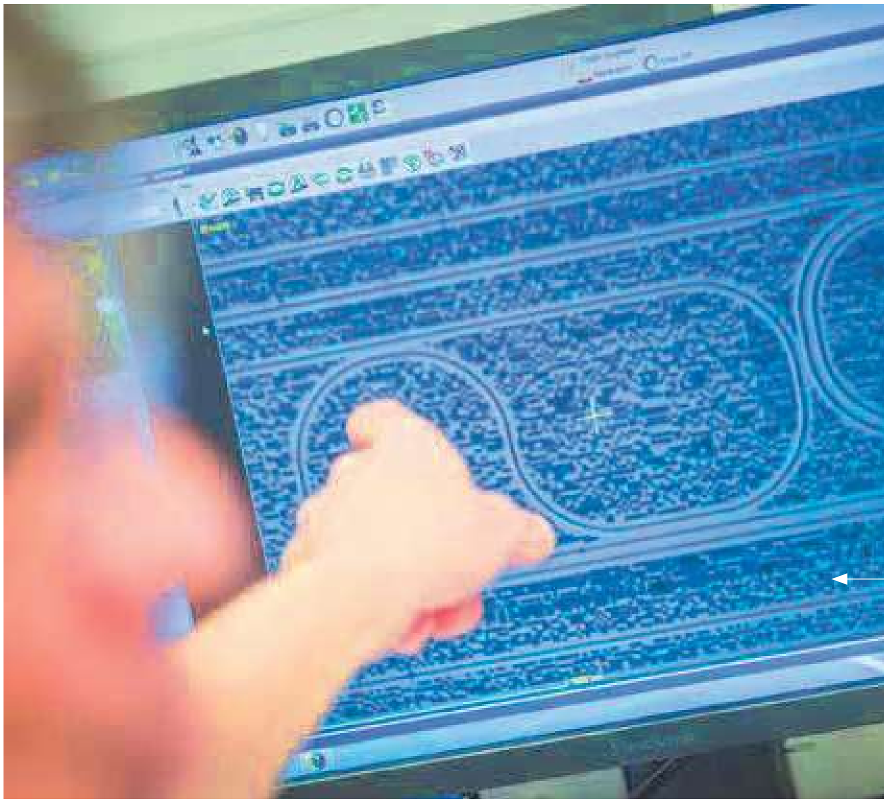

MICROSCOPE VIEW OF THE PHOTONIC MZI CIRCUIT DESIGNED AND PRODUCED AT CEA-LETI FOR ALCOHOL DOSE TITRATION

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TESTING THE VERY FIRST PROTOTYPE OF A PHOTONIC SENSOR FOR ALCOHOL DOSE TITRATION

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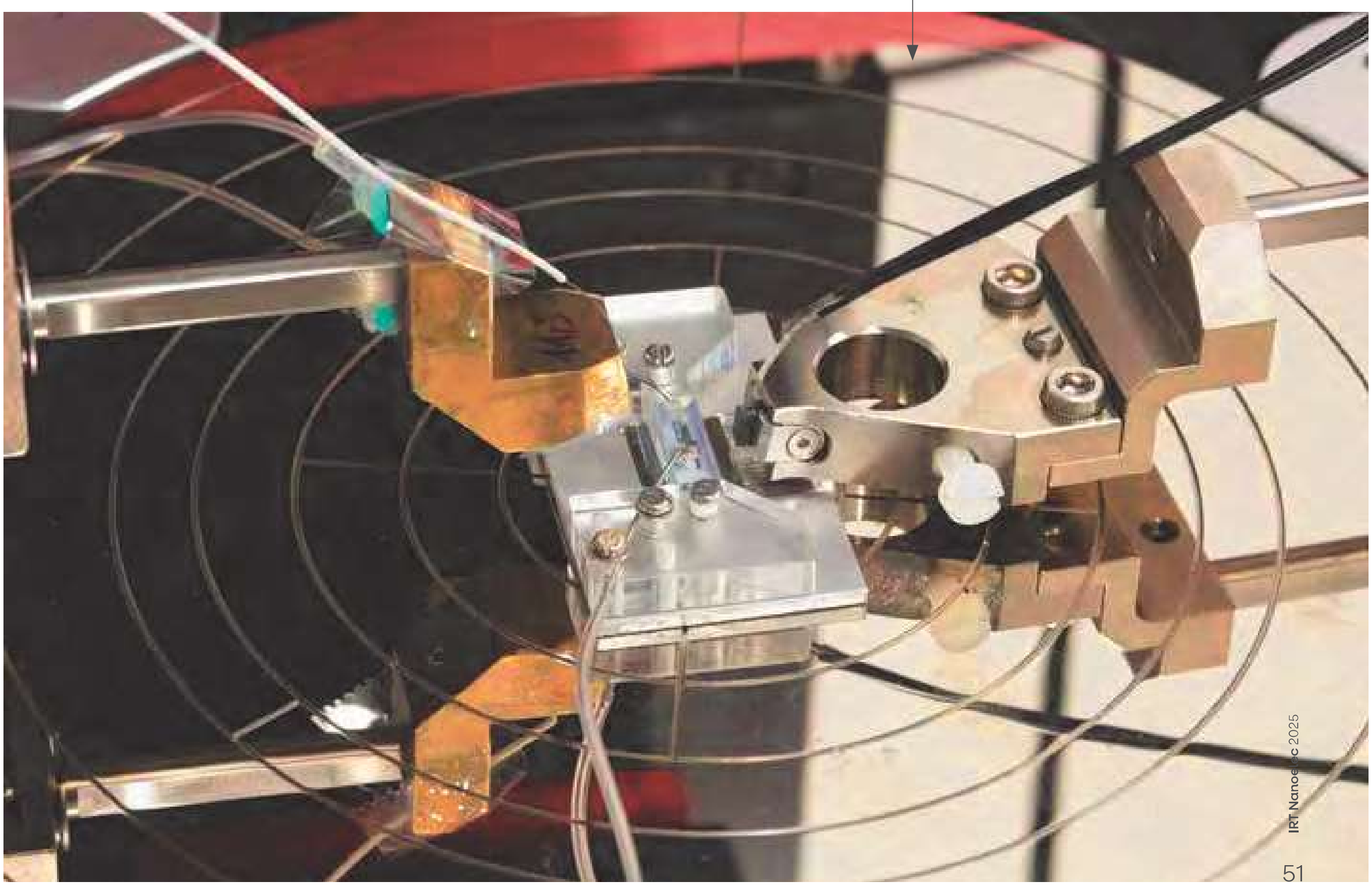

Micro light-emitting diodes

How to Enhance MicroLED Performance.

Within Nanoelec, a team from CEA, CNRS and the Public University of Navarre conducted a synoptic review of III-V Semiconductor Technology to enhance performance of micro light-emitting diodes (microLEDs).

III-V semiconductors, known for their optoelectronic properties and versatile engineering capabilities, play a crucial role in the fabrication of microLEDs. Recent advances in research underscore the fact that the optoelectronic performance of microLEDs can be significantly enhanced using various strategies, such as passivation and distributed Bragg reflectors (DBRs), the incorporation of metamaterials and plasmonics, and the integration of 2D materials. The study was published in Advanced Optical Materials.[4]

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4. Mouloua, D., Martin, M., Beruete, M., Jany, C., Hassan, K., & Baron, T. (s. d.). Exploring Strategies for Performance Enhancement in Micro-LEDs : A Synoptic Review of III-V Semiconductor Technology. Advanced Optical Materials, n/a(n/a), 2402777. https://doi.org/10.1002/adom.202402777

Photonic interconnection for AI

The LEAF Light product family.

The Scintil Photonics start-up, which uses technologies developed within Nanoelec, is focusing on a multi-wavelength a laser source dedicated to co-packaged optics.

"This circuit will in particular be used to ensure interconnections between routing (switch) and computing (GPU) components, and support the growing needs for communication between AI and Machine Learning chips," explains Matthew Crowley, CEO of Scintil Photonics, which is positioning itself on the artificial intelligence and super-computing markets.

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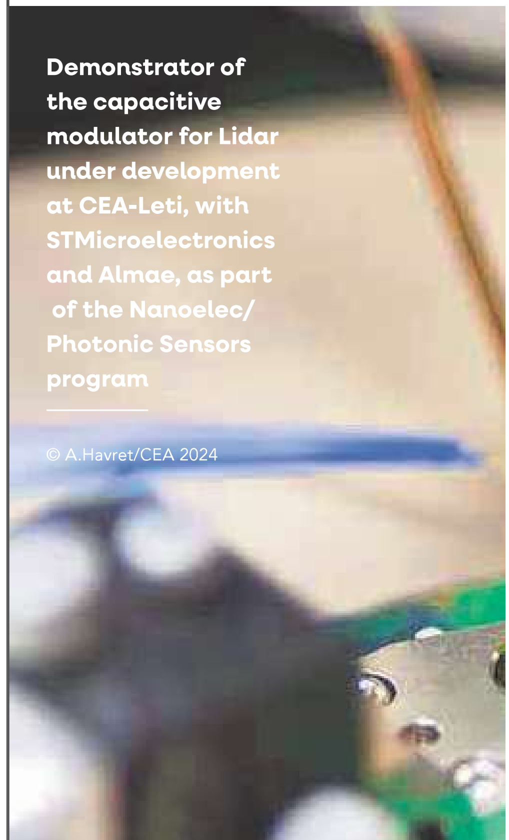

Demonstrator of the capacitive modulator for Lidar under development at CEA-Leti, with STMicroelectronics and Almae, as part of the Nanoelec/ Photonic Sensors program

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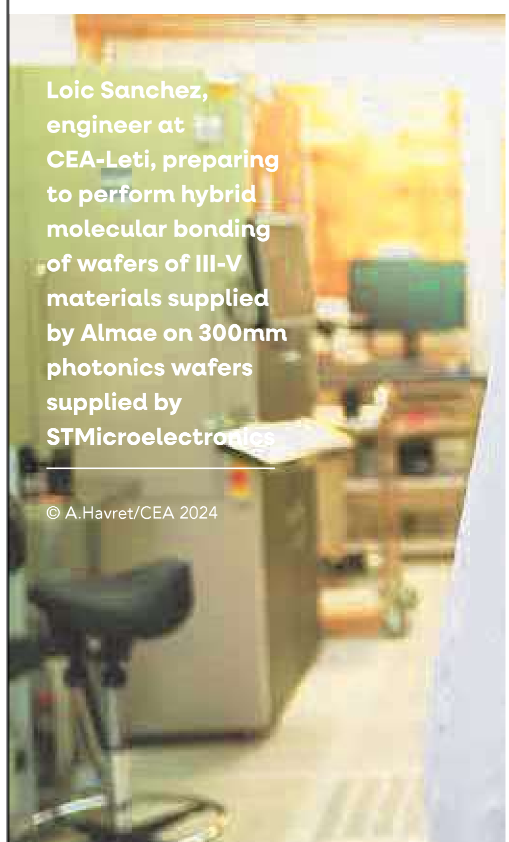

Loic Sanchez, engineer at CEA-Leti, preparing to perform hybrid molecular bonding of wafers of III-V materials supplied by Almae on 300mm photonics wafers supplied by STMicroelectronics

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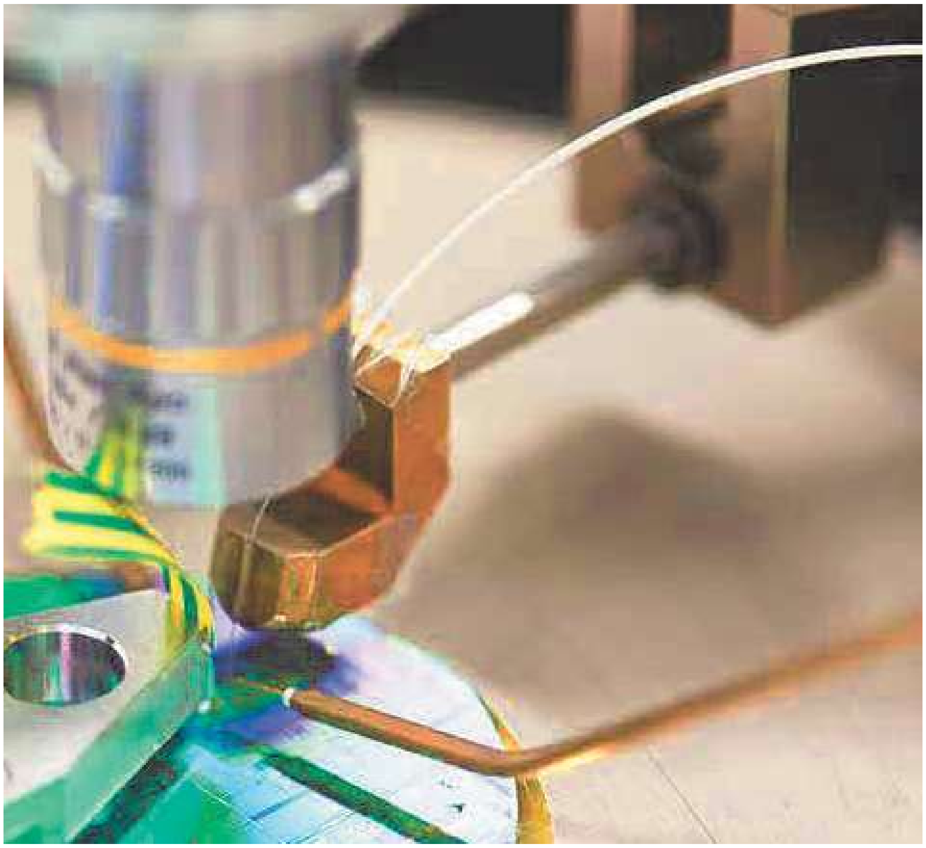
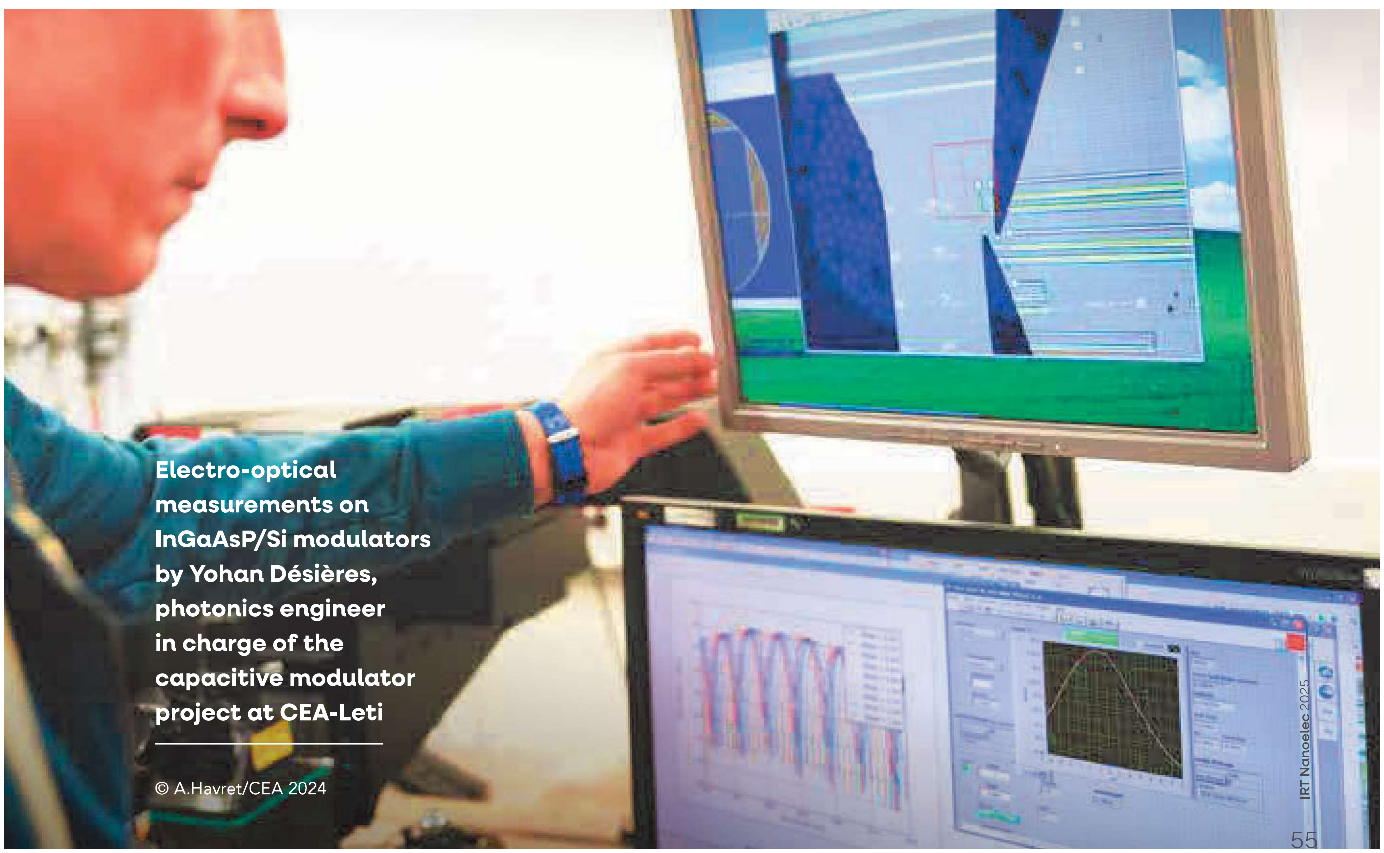


Clément Castan, CMP (chemical & mechanical polishing) engineer at CEA-Leti, loads 300mm silicon wafers into the machine which is used for planarizing before molecular bonding of the IIIV materials

Tristan Faure, technician at CEA-Leti, supervises the III-V materials lithography step for the capacitive modulator demonstrator



Electro-optical measurements on InGaAsP/Si modulators by Yohan Désières, photonics engineer in charge of the capacitive modulator project at CEA-Leti