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Welcome to the first M3NIR newsletter!

What is M3NIR?

M3NIR Project: Next-Generation Mid-IR Sensing

Traditional mid-IR sensors typically use Fourier Transformation IR (FTIR) setups. However, the technology has advanced significantly with the development of mid-IR lasers, particularly Quantum Cascade Lasers (QCLs). QCLs enhance the signal-to-noise ratio by up to two orders of magnitude and provide direct access to the molecular fingerprint region of analytes. As a result, QCL-based sensing is increasingly being used in various commercial applications due to its high performance and cost-effectiveness.

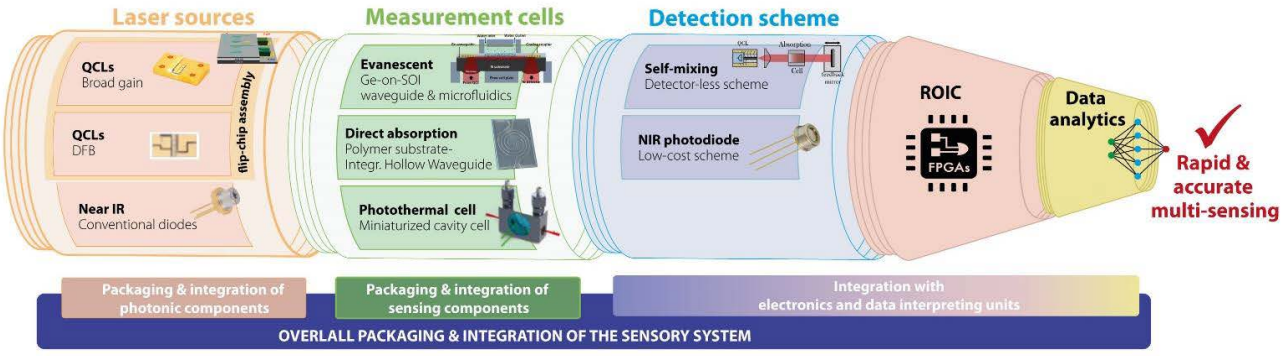
The **M3NIR** (Integrated, **M**odular, **M**ultisensing, **M**id- and **N**ear- **IR** sensing platform) project is developing a concept for integrating all necessary components into advanced sensory systems. These systems are designed to detect multiple species and target high-impact applications. Key developments include:

- **Optimized QCLs**: For enhanced sensing and integration.
- **Additional Components**: Microfluidic devices, novel waveguide designs, electronics, and signal processing units.
- **Integration Schemes**: Balancing performance and cost.

Benefits of Mid-IR Absorption-Based Spectroscopy

Mid-IR absorption-based spectroscopy (2.5–25 µm) is ideal for directly sensing trace gas analytes due to its ability to provide detailed molecular information. The miniaturization of optical components has further enhanced the utility of optical sensing techniques, making them compact, portable, easy-to-use, and robust while maintaining high accuracy, sensitivity, and selectivity.

By integrating these advanced technologies, the **M3NIR** project aims to develop next-generation sensing systems with strong commercialization potential, offering high performance and cost-effective solutions across various applications.



Key Innovations

- **Energy Efficiency**: Significant reduction in energy consumption, size, weight, and cost by using a self-mixing detection scheme, eliminating the need for high-performance detectors in the mid-IR range.
- **Demonstration**: The project will showcase its achievements at Technology Readiness Level 5 (TRL5) in three use cases:
- **Environmental Monitoring**: Using drone-mounted gas sensors.
- **Water Analysis**: Employing IoT-compatible sensors.
- **Breath Analysis**: Determining metabolic ratios and monitoring health status.

Project facts & figures:

Short name: **M3NIR**

Full name: Integrated, Modular, Multisensing, Mid- and Near- IR sensing platform.

Duration: 01/01/2023 – 06/30/2026 (42 months).

Project value: Up to 4.999 M. €

Structure: 6 work packages

Consortium: 13 partners out of 9 countries

Coordinator: IMEC

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Results After the First 18 Months

QCL Sources

Within M3NIR, ALPES develops QCLs tailored for integration on a Ge-on-SOI PIC platform developed by IMEC. Ge-on-SOI is widely transparent in the mid-infrared (2-8.5 μm band), the high refractive index allows for dense integration, and efficient heaters can be realized on the platform. The aim is to combine the Ge-on-SOI waveguides with QCL gain chips to make high quality tunable lasers for the mid-infrared with a high yield. Moreover, multiple wavelength bands can be targeted, required for practical applications.

This integration demands close collaboration between ALPES and IMEC. Numerical simulations have defined the required mode structures in QCLs and Ge waveguides on PICs, optimizing the coupling efficiency and guiding the integration strategy. ALPES has provided first sets of DFB-QC and FP-QC chips to IMEC. The next steps involve processing and characterizing dedicated QC chips for flip-chip integration, targeting specific wavelengths for the different M3NIR use cases.

Ge-on-SOI PIC platform

Two different integration approaches were defined, thereby maximizing the availability of QC chips on short-term for hybrid integration experiments, and at the same time defining a more scalable flip-chip integration approach for which customized QC chips are being processed. Several DFB-QCLs have been integrated on sub-mounts for hybrid integration, allowing for high alignment accuracy when coupling to multiple QCLs to Ge-on-SOI waveguides. First assemblies have been characterized, and steps for further improvement have been defined. A detailed thermal model was also developed by ARGO to optimize the cooling and temperature modulation of QCLs. For the Ge-on-SOI PIC platform, initial design efforts by VLC focused on the beam combiner, Distributed Bragg Reflector, and Vernier Rings, to be continued in the next few months.

Passive Ge-on-Si PICs

VLC also undertook the optical design for the passive Ge-on-Si PIC platform for liquid analyzer use case, focusing on creating essential building blocks such as single-mode Ge waveguides, grating couplers, and multimode interference couplers. IMEC handled fabrication on a 2 μm thick Ge-on-Si platform, with the first version of the PIC already fabricated. Ongoing efforts aim to refine the process, achieving fine resolution for grating couplers, while providing smooth waveguide sidewalls.

Self-Mixing Detection

NKUA studied the self-mixing (SM) method to enable detector-less gas sensing by measuring terminal voltage variations caused by optical feedback. The goal is to integrate SM into the breath analysis use case, enhancing energy efficiency by eliminating the need for cooled mid-IR detectors. Efforts are concentrated on improving SM sensitivity, with current setups providing gas concentration sensitivity in the order of 100s ppm at 1 sec integration time. A QCL numerical model is also under development to simulate various SM scenarios, with ongoing validation efforts.

Microfluidics

CHIPSH developed a microfluidics chip for aligning fluidic channels to Ge waveguide structures on the PIC. This will enable a flexible assembly method to evaluate different liquid interaction lengths, while providing leakage during liquid sample insertion. Current chips are produced by milling, while future designs will be based on injection moulding, once designs have been frozen. Testing of different microfluidic designs is currently ongoing.

Electronics

EUL developed the first version of the electronics for M3NIR, for both the TEC (thermo-electric cooler) driver and laser drivers. The electronics offer a serious reduction in size and power consumption, as required for the use case of air quality monitoring on a drone platform from ALTUS.

Data Acquisition

CYRIC initiated discussions on M3NIR platform requirements, dashboard visualizations, and machine learning models. Data upload protocols were defined, and the M3NIR cloud platform was developed for data retrieval, storage, and visualization. A dashboard demo was shared early in the project, and further development of visualization tools and machine learning models is ongoing.

Use Case 1: Environmental sensing

A drone-mounted ICAPS-based sensor (Interferometric Cavity-Assisted Photothermal Spectroscopy, ICAPS) is being developed through collaboration among TUW, ALPES, EUL, CYRIC, and ALTUS. The sensor utilizes an optical cavity for sensitive gas detection via photothermal spectroscopy. ALPES provided DFB-QCLs as excitation sources, with EUL developing the necessary electronics. The set-up is being constructed on an optical table by TUW, and following successful testing the procedures for mounting the sensor module on a drone platform from ALTUS will be initiated.

Use Case 2: Liquids analysis

The development of a miniaturized platform for ionic species detection in water involves collaboration among TUW, IMEC, VLC, CHIPSH, ALPES, and BADGER. The platform uses mid-IR dispersion spectroscopy with Ge waveguides in MZI structures. VLC designed waveguide components, being manufacturing by IMEC. Testing and benchmarking of the sensor are planned at TUW, after integration with the microfluidics from CHIPSH. Next steps will be to test the system on real life samples by BADGER, which could include river water as well as wastewater effluent and potentially wastewater influent.

Use Case 3: Exhaled breath analysis

The M3NIR exhaled breath analyser is designed to detect Helicobacter pylori infection by identifying the presence of 13CO2 in exhaled breath following the administration of urea labeled with 13C which is metabolized by H. pylori. The sensor, developed by UULM, ALPES, IMEC, NKUA, EUL, and CYRIC, integrates mid-IR absorption with self-mixing detection, offering a potentially low cost and miniaturized solution. UULM designed the substrate-integrated hollow waveguides (iHWG) for optimal interaction with the target analytes, and IMEC is integrating the necessary components on the Ge waveguide PIC platform. Once the different building blocks are available, the sensor module will be validated by UULM.

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M3NIR Dissemination and Communication (Events)

Our consortium has actively presented the **M3NIR** project at number prominent events throughout the year. These events provided an excellent platform to showcase our innovative solutions and engage with the scientific community, industry professionals, and potential stakeholders. Here are the details of some of the events where the **M3NIR** project was presented:

1. **OFC24**: Held in San Diego on 26 March 2023, VLC Photonics set up Booth 5219. This event targeted the scientific community, including academia and industry, with an estimated 13,000 participants from over 70 countries and 540 exhibiting companies.

2. **LASER World of PHOTONICS Munich**: Held in Munich, Germany, on 27 June 2023, Alpes Lasers and VLC Photonics participated with booths, including Booth A2.240. This event attracted 40,000 visitors from 70 countries.

3. **International Conference on Advanced Vibrational Spectroscopy (ICAVS12)**: Held in Krakow, Poland, on 27 August 2023, TU WIEN participated with a presentation. This event targeted the scientific community and had approximately 500 participants.

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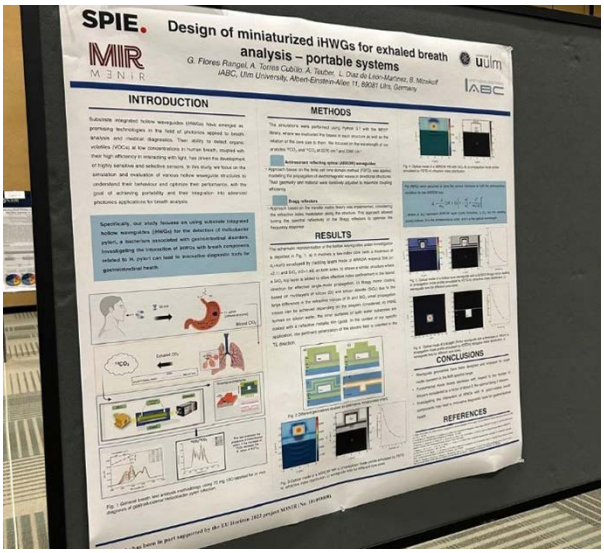
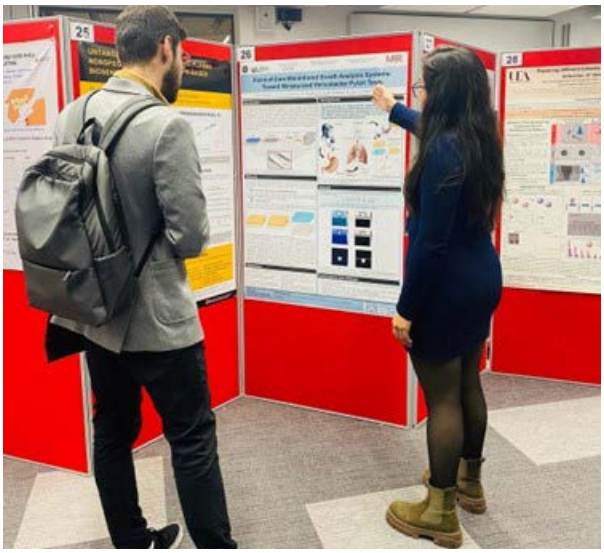
4. **SPIE Photonics West**: Held on 28 January 2024, UULM presented a poster and oral presentation on the design of miniaturized iHWGs for exhaled breath analysis and the detection of gastric cancer via exhaled breath analysis. This event hosted 20,000 participants from 85 countries, with 1,400 exhibitors and over 4,500 presentations.

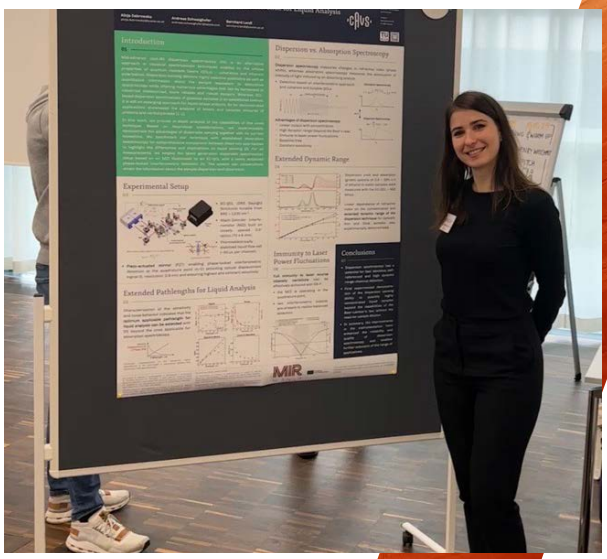


5. **XVI EUROPT(R)ODE**: Held on 24 March 2024 in Birmingham, UK, UULM presented a poster on point-of-care mid-infrared breath analysis systems. This event attracted 250-300 participants.



6. **Analytica**: Held in Munich, Germany, on 19 April 2024, CHIPSH set up Booth A3.313B. This event targeted the scientific community, including academia and industry, with 35,000 visitors from 120 countries.

7. **17. Interdisziplinaeres Doktorandenseminar**: Held in Freiburg im Breisgau, Germany, on 11 March 2024, TU WIEN participated with a poster on Mid-IR Dispersion Spectroscopy - A New Avenue for Liquid Analysis. This event targeted the scientific community, including academia and industry.



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The upcoming Events/Meetings where M3NIR will be presented:

- The IEEE Photonics Conference (IPC) which will be held from 10-14 November 2024 in Rome, Italy https://ieee-ipc.org/
- ECOC2024 https://www.ecocexhibition.com/ 24/09/2024
- PIC Summit Europe https://www.etr.events/picsummiteurope/5506174 15/10/ 2024
- Optical Latin America Optics and Photonics Conference 10/11/2024 Optica Latin America Optics and Photonics Conference | Optica
- IEEE Electronics Packaging Technology Conference (EPTC) 03/12/2024 EPTC (eptc-ieee.net)

Consortium:

- INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM (IMEC), Belgium,
- ETHNIKO KAI KAPODISTRIAKO PANEPISTIMIO ATHINON (NKUA), Greece,
- VLC PHOTONICS SL (VLC), Spain,
- MICROFLUIDIC CHIPSHOP GMBH (CHIPSH), Germany,
- TECHNISCHE UNIVERSITAET WIEN (TUW), Austria,
- ARGOTECH AS (ARGO), Czechia,
- EULAMBIA ADVANCED TECHNOLOGIES MONOPROSOPI ETAIRIA PERIORISMENIS EFTHINIS (EUL), Greece,
- UNIVERSITAET ULM (UULM), Germany,
- S CAN GMBH (S CAN), Austria,
- ALTUS LSA COMMERCIAL AND MANUFACTURING SA (ALTUS), Greece,
- UAB METIS BALTIC (METIS), Lithuania,
- CY.R.I.C CYPRUS RESEARCH AND INNOVATION CENTER LTD (CyRIC), Cyprus,
- (ALPES LASERS SA, (ALPES), Switzerland.

For more information:

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