OPTAPHI

An EU Marie Skłodowska-Curie ITN

European Double Doctorate Training Network

Optical Sensing using Advanced Photo-Induced Effects

Second Call for Applicants

Cork Institute of Technology
Cork, Ireland

Technische Universität Wien
Vienna, Austria

Université de Montpellier
Montpellier, France

Politecnico di Bari
Bari, Italy

Università degli studi di Bari Aldo Moro
Bari, Italy

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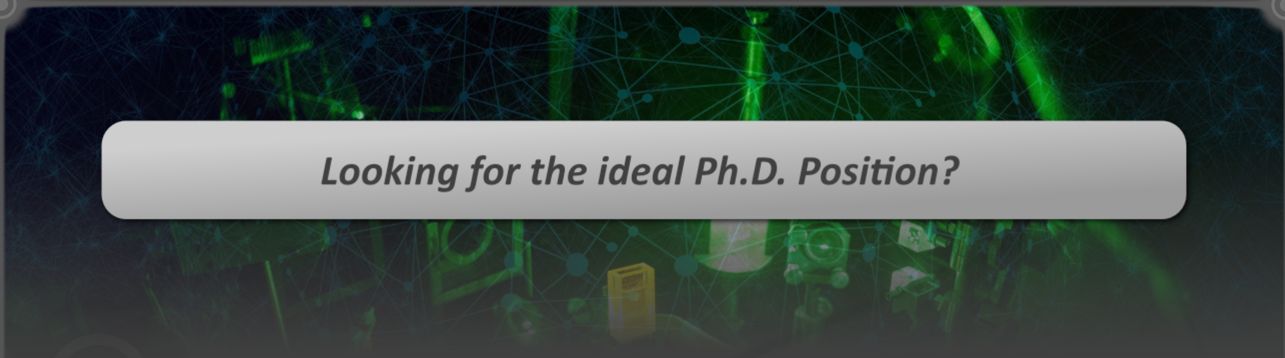

Looking for the ideal Ph.D. Position?

Do YOU want to:

- *Be a Marie Skłodowska-Curie Fellow (Early Stage Researcher)*
  with accompanying salary and benefits
- *Study in 2 European countries*
  (Ireland / Italy / Austria / France)
- *Get a Ph.D. degree awarded from 2 institutions*
  (Double Doctorate/Co-tutelle)
- *Undertake an exciting, multi-disciplinary research project*
  combining spectroscopy with laser design and fabrication
- *Be part of a diverse team of 14 ESR Fellows*
  working towards common goals, with network-wide training events

Do you meet the MSCA Eligibility Rules:

- *Researchers may be of any nationality. However, they must undertake physical, trans-national mobility (i.e. move from one country to another) when taking up their appointment.*
- *The researcher must not have resided or carried out his/her main activity (work, studies, etc.) in the country of his/her host organisation for more than 12 months in the 3 years immediately prior to his/her recruitment. (Short stays, such as holidays, are not taken into account).*
- *ESRs shall, at the date of recruitment, be in the first four years* of their research careers, and must not have been awarded a doctoral degree.*

**Measured from the date when he/she obtained the degree which would formally entitle him/her to embark on a doctorate.*

Then visit **WWW.OPTAPHI.EU** *to apply!*

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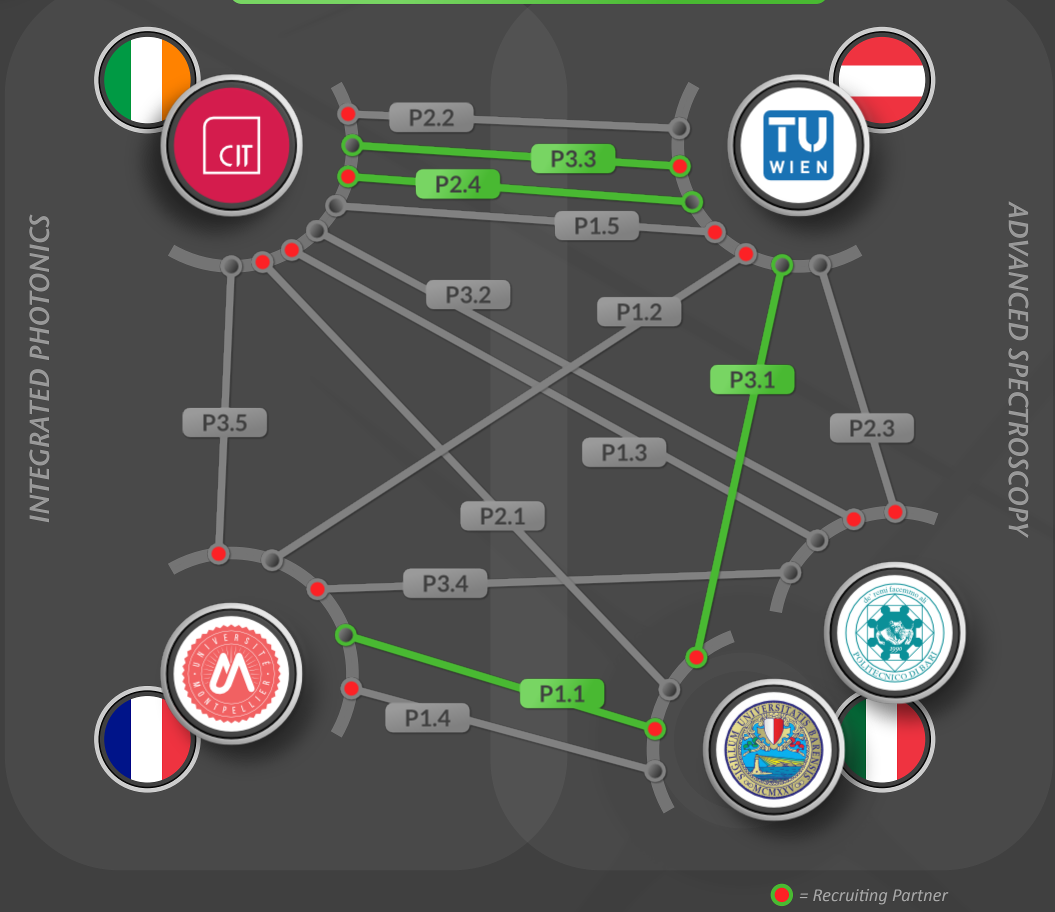
Postgraduate Training in the OPTAPHI Network

- 14 individual Early Stage Researcher (ESR) research projects
- Fellowships are for a maximum of 36 months
- Each ESR is recruited by 1 partner institute for the full 36 months, and will spend a minimum of 1 year at a co-host partner
- Projects are grouped into 3 research themes (Work Packages):
  Environmental Sensing, Agri-Food Analysis, Industrial Process Monitoring

Projects in green are still available in Call 2



Network-Wide Training Events in OPTAPHI

- Workshop 1 — Montpellier, France
- Summer School — Sicily, Italy
- Workshop 2 — Vienna, Austria
- Workshop 3 — Cork, Ireland
- Final Conference — Bari, Italy

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About the OPTAPHI Partners

Cork Institute of Technology   Cork, Ireland [Coordinators]

*The Centre for Advanced Photonics & Process Analysis (CAPPA, **www.cappa.ie**) spearheads photonics research at CIT (**www.cit.ie**). The Nanophotonics group within CAPPA uses nanoscale devices to control and manipulate light, primarily through nanostructuring high refractive index silicon based materials with techniques such as electron beam lithography, and is one of the leading authorities on disorder and loss in Photonic Crystals. A Memorandum of Understanding with University College Cork allows CAPPA personnel to access the world-class state of the art cleanroom facilities of the Tyndall National Institute (**www.tyndall.ie**).*

Politecnico di Bari   Bari, Italy

*Politecnico di Bari (**www.poliba.it**) consists of five Departments and 18 spin-off companies, and is one of the three national Italian Polytechnics educating architects, engineers and industrial designers. The Dipartimento di Ingegneria Elettronica (DEI, **dei.poliba.it**), in which the OPTAPHI research will be carried out, covers the fields of medical, IT telecommunication, automation, electrical and electronic engineering. The Electromagnetic Fields research group is composed of 10 researchers with great experience in the design and characterization of microwave and photonic devices.*

Università degli studi di Bari Aldo Moro   Bari, Italy

*The University of Bari Aldo Moro (**www.uniba.it**) is one of the largest universities in Italy, attended by more than 60,000 students, with 16 PhD schools at the graduate level. The OPTAPHI activities will be carried out within the PolySense Lab group of the Physics Department. The group comprises 12 researchers and carries out interdisciplinary research activities in the fields of laser spectroscopy, optical gas sensing and development of semiconductor laser sources, with a focus on QEPAS for the last 10 years. In April 2017, the PolySense joint-research lab was created in collaboration with Thorlabs, devoted to the development of innovative gas sensing systems.*

Technische Universität Wien   Vienna, Austria

*Technische Universität Wien (**www.tuwien.at**) was founded in 1815 and is Austria's leading research and higher education establishment on natural sciences and engineering. TU Wien's mission is "Technology for People". Our focus is not only on the balance of basic research with applied research, but the high quality results from excellent research and close cooperation with economy. The research division on environmental and process analytical chemistry, headed by Prof. Dr. Bernhard Lendl, focuses on advanced analytical sciences through the development of novel analytical techniques and instrumentation based on infrared and Raman spectroscopy.*

Université de Montpellier   Montpellier, France

*Université de Montpellier (**www.umontpellier.fr**) is a research-intensive university where education and research cover most of the scientific and technological fields. UM gathers around 43,000 students and 4,618 staff with an overall budget of 385 M€. Research is structured into 76 laboratories, most of which are in partnership with well-recognised French research organisations such as CNRS, IRD, INRA or CIRAD. The OPTAPHI work will be carried out in Institut d'Electronique et des Systèmes (IES, **nanomir.edu.umontpellier.fr**), a joint research unit from UM and CNRS (UMR5214), a world leader in the development of GaSb-based optoelectronic devices.*

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Scientific Overview

Photonics, the science of generating and manipulating light, is a key technology of the 21st century; it has been identified by the European Investment Bank as being one of the "**building blocks of the next digital revolution**". Photonics underpins all aspects of modern society, including optical telecommunications, biophotonics, medical devices, optical sensors and materials processing, with a global market expected to reach €615 billion by 2020 and growing. **Photonic sensors** are a key element of the sector; measurement of molecular-specific optical transitions allows qualitative and quantitative analysis in-situ, without the need to chemically prepare or damage the sample in question, and hence is hugely attractive for a wide range of applications, from **Process Analytical Technology (PAT)** to **biomedical diagnostics**.

Due to Europe's strong activity in optical sensing and the large variety of applications, it is becoming increasingly difficult for all sectors to find highly skilled photonics graduates, particularly at the interfaces between sectors. In particular, optical sensing is intrinsically a **multi-disciplinary topic**, requiring expertise in chemistry, physics and engineering, making truly disruptive innovation difficult within a traditional Ph.D. project. The **OPTAPHI network** (pronounced opta-fy) aims to address this by training a cohort of doctoral students in the complementary fields of **advanced spectroscopy** and **integrated optics**. Specifically, the focus is on the methods of photo-acoustic and photo-thermal spectroscopy, and the compact semiconductor lasers and integration techniques that enable sensors based on these.

Photo-Acoustic and Photo-Thermal Spectroscopy

The absorption of light by a sample (gas, liquid, solid) causes the sample to heat up; if the pump light is modulated, this produces a sequence of gas heating and cooling, leading to the generation of thermal and acoustic (sound) waves. Quartz Enhanced Photo-Acoustic Spectroscopy (QEPAS) and Photo-Thermal Spectroscopy (PTS) are ultra-sensitive techniques based on the detection of these acoustic and thermal waves. In QEPAS, a quartz tuning fork is used to detect the acoustic waves created in a gas sample, and is immune to external acoustic noise. PTS detects the refractive index change caused by the absorption-induced heating, using a Fabry-Pérot interferometer. Both techniques can potentially detect extremely low concentrations, at parts per trillion levels or less. PTS can also be applied to liquid sensing and, in combination with AFM, to near-field IR imaging.

Semiconductor Lasers and Integrated Photonics

The gases which can be detected by QEPAS and PTS depend on the pump laser used, the wavelength of which must be tailored to the absorption lines of the target gas. In order to realise compact, portable and low-cost sensors, these lasers need to have the small footprint of semiconductor lasers, similar to those used in e.g. the telecoms industry, and be closely integrated with the QEPAS/PTS cell. OPTAPHI will develop new hybrid photonic crystal lasers, long wavelength quantum cascade lasers, and III-V lasers grown on silicon, with new wavelength locking mechanisms and analysis techniques, to greatly reduce system size and improve robustness of the optical sensors. Regarding near-field IR imaging it will also conceive new transducers for simultaneously detecting thermal and chemical properties of solid samples with nanometre resolution.

OPTAPHI Scientific Objectives

- Demonstrate novel **Quartz Enhanced Photo-Acoustic Spectroscopy** (QEPAS) and **Photo-Thermal Spectroscopy** (PTS) configurations with improved sensitivity and compactness
- Demonstrate improved detection of benzene, toluene, ethylbenzene and xylene (**BTEX**) and **propane** exploiting long wavelength 10+ µm laser sources
- Demonstrate highly sensitive Photo-Thermal Spectroscopy for **liquid analysis** for the first time
- Improve the compactness, robustness and power consumption of QEPAS to allow use on **Unmanned Aerial Vehicles**
- Demonstrate new methodologies to improve the sensitivity of PTS and QEPAS in the second overtone band, thereby allowing the use of **low-cost telecoms components**

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OPTAPHI Ph.D. Projects available in Call 2

Project 1.1	Compact diode-laser based QEPAS sensors for UAVs
Project 2.4	Intra-cavity PTS with optical feedback for isotopic verification of food origin
Project 3.1	Intra-cavity QEPAS for isotope analysis
Project 3.3	Trace water detection in organic solvents using PTS

Other (filled) Ph.D. Projects in OPTAPHI

Project 1.2	Long wavelength PTS for BTEX detection
Project 1.3	Photonic crystal hybrid lasers for intra-cavity QEPAS & PTS
Project 1.4	Long-wavelength QCLs for BTEX and propane detection through QEPAS
Project 1.5	Generation & detection of photo-thermal & photo-acoustic waves in solids for advanced near-field IR imaging
Project 2.1	Ultra-compact QEPAS by integrating cantilever hybrid laser with quartz tuning fork
Project 2.2	QEPAS and PTS using low cost telecoms wavelength lasers for food analysis
Project 2.3	High Q-factor photonic cavities for PTS
Project 3.2	2D materials for hybrid laser wavelength tuning
Project 3.4	Hybrid III-V lasers on silicon for low-cost MIR gas sensing
Project 3.5	Single-mode interband cascade lasers for petro-chemical process monitoring

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OPTAPHI Work Packages and Research Skills

WP1: ENVIRONMENTAL SENSING

Lead Beneficiary: UM

- **Project 1.1 [UNIBA + UM]:** Compact diode-laser based QEPAS sensors for UAVs
- **Project 1.2 [TU-WIEN + UM]:** Long wavelength PTS for BTEX detection
- **Project 1.3 [CIT + POLIBA]:** Photonic crystal hybrid lasers for intra-cavity QEPAS and PTS
- **Project 1.4 [UM + UNIBA]:** Long-wavelength QCLs for BTEX and propane detection through QEPAS
- **Project 1.5 [TU-WIEN + CIT]:** Generation & detection of PT & PA waves in solids for advanced near-field IR imaging

WP2: AGRI-FOOD ANALYSIS

Lead Beneficiary: TU-WIEN

- **Project 2.1 [CIT + UNIBA]:** Ultra-compact QEPAS by integrating cantilever hybrid laser with quartz tuning fork
- **Project 2.2 [CIT + TU-WIEN]:** QEPAS and PTS using low cost telecoms wavelength lasers for food analysis
- **Project 2.3 [POLIBA + TU-WIEN]:** High Q-factor photonic cavities for PTS
- **Project 2.4 [CIT + TU-WIEN]:** Intra-cavity PTS with optical feedback for isotopic verification of food origin

WP3: INDUSTRIAL PROCESS MONITORING

Lead Beneficiary: UNIBA

- **Project 3.1 [UNIBA + TU-WIEN]:** Intra-cavity QEPAS for isotope analysis
- **Project 3.2 [POLIBA + CIT]:** 2D materials for hybrid laser wavelength tuning
- **Project 3.3 [TU-WIEN + CIT]:** Trace water detection in organic solvents using PTS
- **Project 3.4 [UM + POLIBA]:** Hybrid III-V lasers on silicon for low-cost MIR gas sensing
- **Project 3.5 [UM + CIT]:** Single-mode interband cascade lasers for petrochemical process monitoring

		WP1: ENVIRONMENTAL SENSING					WP2: AGRI-FOOD ANALYSIS				WP3: INDUSTRIAL PROCESS MONITORING				
PhD AWARDING ENTITIES	ESR Project No.:	P1.1	P1.2	P1.3	P1.4	P1.5	P2.1	P2.2	P2.3	P2.4	P3.1	P3.2	P3.3	P3.4	P3.5
	Recruiting Partner:	UNIBA	TU-WIEN	CIT	UM	TU-WIEN	CIT	CIT	POLIBA	CIT	UNIBA	POLIBA	TU-WIEN	UM	UM
	Co-Hosting Partner:	UM	UM	POLIBA	UNIBA	CIT	UNIBA	TU-WIEN	TU-WIEN	TU-WIEN	TU-WIEN	CIT	CIT	POLIBA	CIT
	For All Projects:	**Planned Starting Month:** Oct/Nov 2020 **Duration:** 36 months													
SENSOR TYPE	QEPAS:	●		●	●	●	●	●			●	●		●	●
	Photo-Thermal:		●	●		●		●	●	●		●	●	●	
LASER TYPE	Diode Laser:	●				●		●							
	QCL/ICL:		●		●	●					●		●		●
	Hybrid Laser:			●		●	●		●	●		●		●	●
WAVELENGTH RANGE	swNIR (<1.8 µm):			●		●	●	●				●			
	NIR/MIR (1.8 – 10 µm):	●				●			●	●	●		●	●	●
	LWIR (>10 µm):		●		●	●									
APPLICATION FOCUS AREA	Environmental Sensing:	●	●	●	●	●	●					●		●	
	Agri-Food Analysis:					●	●	●	●	●					●
	Ind. Process Monitoring:			●		●	●				●	●	●	●	●

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Work Package 1: ENVIRONMENTAL SENSING

This workpackage will develop a sensing system that uses the new lasers developed by CIT, POLIBA and UM in new QEPAS systems realised by UNIBA and a PTS system realised by TU-WIEN. The long wavelength QCLs will be used for BTEX (benzene, toluene, ethylbenzene, xylene) detection at λ = ~13.365 μm, the DFB lasers, hybrid lasers and lasers on silicon for methane detection at λ = ~1.6 μm and 2.3 μm. Depending on the maturity of the technologies, one (or possibly more) device(s) will be chosen for tests at the partner organisations. Laboratory tests will be made for the others.

The work is broadly divided into three tasks: Task 1.1 will develop a compact shoe-box sized QEPAS platform suitable for portable real-world applications such as environmental monitoring; Task 1.2 will focus on BTEX detection using the developed QCLs; while Task 1.3 will target methane leak detection using very compact QEPAS systems for deployment on UAVs (Unmanned Aerial Vehicles, i.e. drones).

WP1 Objectives

- Realisation of BTEX and propane QEPAS and PTS sensors exploiting QCL sources operating in the 13-20 μm wavelength range and reaching parts per billion sensitivity ranges
- Realisation of ultra-compact (below 1 dm³) QEPAS sensors implementing novel methods to couple near-IR lasers and acoustic detection module targeting UAV sensing applications

Project 1.1	Project 1.2	Project 1.3	Project 1.4	Project 1.5
Compact diode-laser based QEPAS sensors for UAVs	Long wavelength PTS for BTEX detection	Photonic crystal hybrid lasers for intra-cavity QEPAS & PTS	Long-wavelength QCLs for BTEX and propane detection through QEPAS	Generation & detection of PT & PA waves in solids for near-field IR imaging
Links with:	Links with:	Links with:	Links with:	Links with:
WP2: P2.1, P2.2, P2.4	WP2: P2.4	WP2: P2.1, P2.2, P2.3	WP2:	WP2: P2.1, P2.2, P2.4
WP3: P3.1, P3.2, P3.4, P3.5	WP3: P3.5	WP3: P3.2, P3.3, P3.4	WP3: P3.1, P3.5	WP3: P3.1, P3.3

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Work Package 2: AGRI-FOOD ANALYSIS

The goal of this workpackage will be the realisation of a shoe-box sized demonstrator PTS and/or QEPAS sensor capable of monitoring the quality of foods. As target gas analytes, basic amines (in particular ammonia) as an indicator for food degradation (fish) as well as diacetyl as a quality parameter for brewing have been chosen. These analytes were selected because of i) their real-world relevance as indicated by the needs of the industrial partners and ii) because different modulation techniques need to be developed for measuring ammonia (resolved and thus sharp ro-vibrational lines) and diacetyl (non-resolved and thus broad absorption bands), respectively. The demonstrator shall be validated using spiked samples as well as appropriate reference analytics (gas and ion chromatography). Concerning liquid phase analysis, a PTS system based on a Mach-Zehnder interferometer will be developed and applied for measuring different proteins in aqueous solutions like milk samples. The mid-IR spectra of proteins and especially the amide I band related to the C=O bond are indicative for the secondary structure of a protein. OPTAPHI will investigate the possibility to quantify up to three proteins simultaneously and compare the results obtained using the PTS technique with data recorded using direct spectroscopy using broadly tunable external cavity QCLs.

WP2 Objectives

- Demonstration of high sensitivity PTS for detection of diacetyl in beer (headspace) at ppm sensitivity levels
- Realisation of shoe-box size systems for detection of ammonia using integrated photonic transducers

Project 2.1

Ultra-compact QEPAS by integrating cantilever hybrid laser with quartz tuning fork

Links with:

WP1	WP3
P1.1	P3.2
P1.3	P3.3
P1.5	P3.4

Project 2.2

QEPAS and PTS using low cost telecoms wavelength lasers for food analysis

Links with:

WP1	WP3
P1.1	P3.2
P1.3	
P1.5	

Project 2.3

High Q-factor photonic cavities for PTS

Links with:

WP1	WP3
P1.3	P3.2
	P3.3
	P3.4
	P3.5

Project 2.4

Intra-cavity PTS with optical feedback for isotopic verification of food origin

Links with:

WP1	WP3
P1.1	P3.1
P1.2	P3.3
P1.5	P3.5

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Work Package 3: INDUSTRIAL PROCESS MONITORING

The goals of this workpackage will be the development of novel sensing approaches and laser sources aimed at highly sensitive detection of gas and liquid samples involved in industrial processes. Sensing approaches like intra-cavity QEPAS for highly sensitive target gas measurements or PTS for detection of water in organic solvents will be developed. At the same time, improvement in the laser sources will be pursued by realizing novel hybrid laser and single mode interband cascade lasers.

Tasks will include; an intra-cavity QEPAS sensor with a QCL source, able to target both $^{12}CH_4$ and $^{13}CH_4$ for isotope analysis; a liquid phase PTS Mach-Zehnder interferometer; and a number of novel laser sources such as external cavity hybrid lasers, tunable lasers based on silicon-nitride resonant cavities, GaSb-based laser diodes grown on Si, and single mode interband cascade lasers.

WP3 Objectives

- Realisation of intra-cavity QEPAS and intra-cavity PTS sensing systems with few parts-per-trillion detection limits
- Demonstrate the potential of PTS in liquids by detecting trace amounts of water in organic solvents, a key task in the chemical (pharmaceutical) industry

Project 3.1
Intra-cavity QEPAS for isotope analysis

Links with:

WP1	WP2
P1.1	P2.4
P1.4	
P1.5	

Project 3.2
2D materials for hybrid laser wavelength tuning

Links with:

WP1	WP2
P1.1	P2.1
P1.3	P2.2
	P2.3

Project 3.3
Trace water detection in organic solvents using PTS

Links with:

WP1	WP2
P1.3	P2.1
P1.5	P2.3
	P2.4

Project 3.4
Hybrid III-V lasers on silicon for low-cost MIR gas sensing

Links with:

WP1	WP2
P1.1	P2.1
P1.3	P2.3

Project 3.5
Single-mode interband cascade lasers for petro-chemical process monitoring

Links with:

WP1	WP2
P1.1	P2.3
P1.2	P2.4
P1.4	

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Project 1.1

Recruiting Host

Università degli studi di Bari Aldo Moro

Bari, Italy

Co-Host

Université de Montpellier

Montpellier, France

Supervisor:
Prof. Vincenzo Spagnolo

Supervisor:
Dr. Aurore Vicet

Compact diode-laser based QEPAS sensors for UAVs

In this project, we will design and realize compact diode-based QEPAS sensors. The ESR will realize QEPAS sensing modules exploiting novel diode lasers operating in the range 2-2.5 µm. The diode lasers will be based on the buried-grating design pioneered by UM in the GaSb technology. In this device, a grating is etched in the waveguide before regrowth of the top-cladding layer. The ESR will be involved in the design, processing and characterization of the diode lasers. He/she will qualify their operability on the QEPAS set-ups of UM before implementing them in UNIBA sensing systems. The first part of QEPAS related activity will be dedicated to the design and the realization of the spectrophone to be accommodated into the gas cell. The spectrophone will be composed by a highly innovative custom-made quartz tuning fork (QTF) and a single micro-resonator tube for the sound wave enhancement. Resonance frequencies lower than 32 kHz and high quality factors are required to be able to efficiently detect slow relaxing gases of interest for environmental monitoring, such as methane (CH_4), sulphur dioxide (SO_2) and carbon dioxide (CO_2). The spacing between the two prongs will also play a central role for the final sensor sensitivity. It will be crucial to avoid that a portion of the laser radiation hits the QTF prongs or the micro-resonator tube; otherwise an undesirable non-zero thermo-elastic background noise signal will arise, strongly limiting sensor performance. Thus, the prong spacing will be optimized with respect to the beam profile quality of the developed laser sources. The ESR will also use telecoms lasers as an alternative.

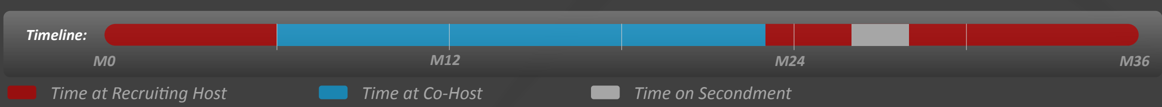
In the second part, we will develop an ultra-compact QEPAS system characterized by a compact size (<1dm^3) and low-power consumption (<1 W). Possible gas targets are H_2O, CH_4, CO_2 or O_3. To further increase the ruggedness of the sensors, solid core fibers will be used to optically coupled the laser source with the QEPAS module. One of the optical windows of the ADM will be substituted with a dedicated fiber connector, thereby realizing an opticless sensing system. The possibility to work at atmospheric pressure will relax constraints related to gas pressure and flow controllers. The QEPAS ADM will also include the gas inlet and outlet ports. An important part of the project will be the realization of dedicated software and control electronics to allow autonomous sensor operation. In the last period of the PhD project the realized sensors will be implemented on a drone to test the capability to measure target gas concentrations in air and in real-time.

Expected Results:

- ***Realization of novel GaSb-based DFB diode lasers***
- ***Realization of an ultra-compact acoustic detection module implementing a QTF with optimized design***
- ***Test and validation of the ultra-compact and low power consumption QEPAS sensor for on-drone sensing***

WP1: Environmental Sensing

Proposed Secondment(s): **Rice University** [USA]



N.B. Timelines and secondments shown are indicative only, and may be subject to change.

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Project 2.4

Recruiting Host | Co-Host

Cork Institute of Technology
Cork, Ireland

Supervisor:
Dr. Liam O'Faolain

Technische Universität Wien
Vienna, Austria

Supervisor:
Prof. Dr. Bernhard Lendl

Intra-cavity PTS with optical feedback for isotopic verification of food origin

The use of high finesse optical cavities can provide dramatic enhancements of the circulating intracavity power and thus of the sensor signals. However, the build-up of optical power in a cavity additionally requires efficient injection of light into the cavity. To achieve this, the laser emission wavelength must be tightly locked to a resonance wavelength of the cavity, which is non-trivial even under laboratory conditions. Optical feedback locking is an elegant solution to this problem. Here, re-injection of light from the cavity into the laser forces the laser to emit light at the injected light's wavelength. To achieve a positive optical feedback (i.e. re-injection of resonant wavelengths only), the classical two mirror design is ill-suited since predominantly non-resonant wavelengths are back reflected. A transparent window inserted into the cavity close to Brewster's angle can be used to couple light into the cavity. In this configuration, only resonant light is reflected back into the laser. With appropriate conditions on the photon lifetime of the laser cavity, optical feedback locking will occur, forcing the laser to match the resonance wavelength of the etalon, even in the presence of outside perturbations. ESR 2.4 will examine and understand this principle and determine the optimum conditions to realise such locking and employ the system in PTS and QEPAS experiments. A key challenge will be to improve the robustness of the intra-cavity system, which is a problem for existing intra-cavity QEPAS. The work will be initially carried at $\lambda = 4.364$ μm to target CO_2 isotopes for determination of the origin of crops. The procedure will be burning the organic matter to produce CO_2, and then measuring the isotope ratio of the produced CO_2. This technique will be extended to as many wavelengths as possible and ESR 2.4 will work with ESRs 1.1, 1.2, 2.3, 3.1 and 3.3.

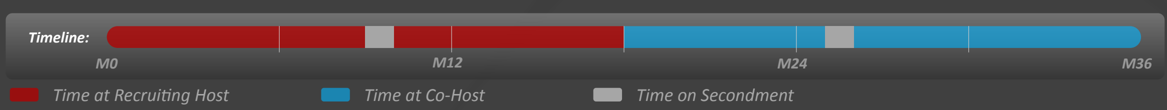
Recent advances in optical microphones (e.g. Xarion) are creating new opportunities for their use in Photothermal spectroscopy. However, existing optical microphones are not optimised for use in PTS. In this project, ESR 2.4 will develop a new microphone in which distributed Bragg Reflectors and photonic crystals will be embedded in a suspended film that will form the diaphragm of the microphone. As the diaphragm flexes, strain will be induced in the nanophotonic device, which will cause changes in the resonance wavelength that will be optically monitored. Working closely with ESR 1.5, ESR 2.4 shall investigate the use of this new microphone for gas sensing and as a transducer in AFM-IR nano-imaging applications.

Expected Results:

- ***Demonstration of enhanced intra-cavity power at $\lambda = 4.364$ μm to target CO_2 isotopes***
- ***Intra-cavity enhancement of QEPAS/PTS for the detection of chemical indicators of food quality***
- ***Realisation of an optical microscope***

WP2: Agri-Food Analysis

Proposed Secondment(s): **Anton Paar GmbH** [Austria]
Teagasc FRC [Ireland]



N.B. Timelines and secondments shown are indicative only, and may be subject to change.

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Project 3.1

Recruiting Host

Università degli studi di Bari Aldo Moro
Bari, Italy

Co-Host

Technische Universität Wien
Vienna, Austria

Supervisor:
Dr. Pietro Patimisco

Supervisor:
Prof. Dr. Bernhard Lendl

Intra-cavity QEPAS for isotope analysis

In this project we will design and realize QCL-based high-finesse spectrometers for integration with QEPAS sensors. Linear cavities will be studied. For injecting the laser in a high-finesse cavity the laser needs to be stabilized. Line locking of the laser to the cavity will be pursued through positive feedback employing a Brewster window set-up.

One of the main challenges for optical techniques is the detection of extremely low-abundance molecules. Among them, isotopes concentration detection, like for example $^{13}CO_2$ or $^{13}CH_4$, assumes high relevance. For tens of years, high-sensitivity radiocarbon detection has been a prerogative of accelerator mass spectrometry (AMS), thus confined to remote "large facilities", and with actual data analysis rates restricted by high costs and slow turnaround times. In this PhD project, we propose innovative solutions for all-optical isotopes detection. The proposed solution is based on quartz-enhanced photoacoustic spectroscopy (QEPAS). We will develop an innovative spectroscopic approach combining the advantages of QEPAS and cavity-enhanced spectroscopy: Intracavity-Quartz-Enhanced Photoacoustic Spectroscopy (I-QEPAS). I-QEPAS was demonstrated by UNIBA for the first time a few years ago for CO_2 detection with a mid-IR (4.3 μm) quantum cascade laser (QCL) and a standard QTF, with a gain in sensitivity of more than two order of magnitude with respect to a standard QEPAS. The implementation of the intracavity sensor will require the realization of compact and stable high-finesse cavities designed to work in the mid-IR range, as well as of proper frequency locking systems allowing the laser to be narrow in linewidth and effectively coupled to the cavity. With respect to the first demonstration, UNIBA, in collaboration with TU-WIEN, aim to reduce the complexity of the I-QEPAS setup and facilitate the optical alignment by replacing the previously used bow-tie cavity with a linear confocal cavity. $^{13}CH_4$ will be targeted using a QCL emitting at 7.7 μm. Optical isolators will be used to prevent unwanted feedback into the laser source. Commercially available powerful QCL and lower losses mirrors will be employed to increase the cavity finesse, i.e. the intra-cavity optical power build up. The implementation of custom QTFs operating at modulation frequencies as low as a few kHz will simplify laser locking to the cavity. TU-WIEN will realize as locking system a Brewster window inside the cavity and resulting positive feedback. Sufficiently wide frequency scans over a molecular absorption line will be performed. UNIBA will focus on the design of the acoustic detection module to be implemented in the cavity, defining the best operating conditions in terms of temperature and pressure and assessing the minimum delta-ratio reachable. This information will allow to properly design the Brewster cavity. Preliminary tests developing a standard QEPAS sensor for methane isotopes ratio measurements will be performed, in order to determine the signal to noise ratio enhancement factor achievable using the intracavity QEPAS approach.

Expected Results:

- ***Realization of a high-finesse resonator integrating a QTF-based acoustic detection module***
- ***Realization of an ultra-compact acoustic detection module***
- ***Test and validation of the intracavity-QEPAS sensor for $^{12}CH_4$ and $^{13}CH_4$ detection***

WP3: Industrial Process Monitoring

Proposed Secondment(s): **Thorlabs GmbH** [Germany]

Timeline: M0 M12 M24 M36

Time at Recruiting Host | Time at Co-Host | Time on Secondment

N.B. Timelines and secondments shown are indicative only, and may be subject to change.

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Project 3.3

Recruiting Host | Co-Host

Technische Universität Wien
Vienna, Austria

Cork Institute of Technology
Cork, Ireland

Supervisor:
Prof. Dr. Bernhard Lendl

Supervisor:
Dr. Liam O'Faolain

Trace water detection in organic solvents using PTS

The task of this ESR will be to explore the potential of using photothermal spectroscopy also for liquid sensing. Major differences between gas and liquid sensing requires the development of dedicated solutions. These need to adapt to the fact that in liquid broad absorption bands prevail and that in solution the solvent itself, to a certain degree, also absorbs mid-IR radiation. Thus factors such as heat capacity and thermal diffusion length of analyte/solvent pairs need to be considered. A first realization of liquid phase PTS will comprise a Mach-Zehnder interferometer which shall incorporate two identical flow cells in the interferometer arms each filled with the sample under investigation. A visible (HeNe) laser will be used and the interferometer operated in the quadrature point employing a balanced detection scheme. One flow cell will be excited by a pulsed mid-IR laser causing a temperature and thus refractive index change which will lead to a detectable phase shift in one arm of the interferometer. Aiming for a maximum photothermal contrast between solvent and analyte the application of measuring traces of water (very strong IR absorber) in organic solvents (week IR absorber) has been selected. The broader motivation of this study is to develop a reagent free alternative to the "Karl-Fischer titration" method, which is the standard technology for measuring trace water content in organic liquids but which can only be applied off-line, consuming sample and generating waste. Complementary analysis of proteins in aqueous solutions will be investigated as a most difficult application (both solvent and analyte show strong absorption) as well. Concerning the latter application, it will be investigated if based on PTS also the secondary structure of proteins can be detected.

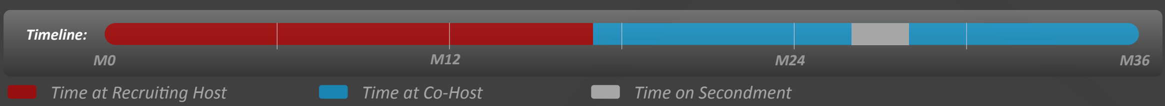
The ESR will then build on the work of ESRs 1.3, 2.1, 2.3, 3.4 to realise liquid compatible integrated optics for liquid operation e.g. photonic crystals and hybrid lasers, for excitation and/or readout. The wavelength of operation will be chosen to minimise absorption by the liquid and the devices redesigned as appropriate. The liquid PTS system will be optimised to allow the use of such components.

***Expected Results*:**

- ***PTS of water in organic solvents using etalon system***
- ***Balanced detection system***
- ***Benchmarking with direct spectroscopy of proteins in water***

WP3: Industrial Process Monitoring

Proposed Secondment(s): **Teagasc FRC** [Ireland]



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Associated Partner Organisations

The following organisations have agreed to accept secondments of OPTAPHI Fellows:

Anton Paar GmbH
Austria

AVL List GmbH
Austria

Eblana Photonics
Ireland

Endress+Hauser GmbH
Germany

ENVEA
France

Rice University
USA

Rinocloud Ltd
Ireland

Teagasc Food Research Centre
Ireland

Thorlabs GmbH
Germany

VPIphotonics GmbH
Germany

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UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO
TECHNISCHE UNIVERSITÄT WIEN
UNIVERSITÉ DE MONTPELLIER

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