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SPOKE N. 4

CUP D33C22001330002

Research proposal

Development of sensors for the detection of impurities in hydrogen

HIGAS - Development of a Hydrogen Impurity Gas Analyzer based on quartz-enhanced photoacoustic Spectroscopy

- Università degli Studi di Bari Aldo Moro - Physics Department
- Dr. Andrea Zifarelli (PI); Prof. Pietro Patimisco (co-PI)
- Proposal duration in months: 12

ROLE IN THE PROJECT	*NAME*	*SURNAME*	*INSTITUTION/ DEPARTMENT*	*QUALIFICATION*	*YOUNG (under 40 al 31.12.2023)*	*F/M*
Principal Investigator	*Andrea*	*Zifarelli*	*Physics Department - University of Bari*	*RTD-A Researcher*	*Yes*	*M*
co-Principal Investigator (PI)	*Pietro*	*Patimisco*	*Physics Department - University of Bari*	*Associate Professor*	*Yes*	*M*
Team Member	*Mariagrazia*	*Olivieri*	*Physics Department - University of Bari*	*Ph.D. Student*	*Yes*	*F*
Team Member	*Aldo Francesco Pio*	*Cantatore*	*Physics Department - University of Bari*	*Ph.D. Student*	*Yes*	*M*

ABSTRACT

The HIGAS project aims at developing an innovative platform for detection of impurities in hydrogen employing quartz-enhanced photoacoustic spectroscopy as sensing technique. The development of hydrogen-related technologies for clean energy production and storage has encountered the obstacles related to the presence of trace contaminants in the hydrogen matrices, strongly affecting the performances of fuel cell systems. Nowadays, the detection and analysis of these impurities is mainly performed employing gas chromatography techniques coupled with different types of detectors. This instrumentation is expensive, characterised by a large footprint and not capable of real-time monitoring. A promising alternative is represented by optical absorption spectroscopy. Among the different techniques, quartz-enhanced photoacoustic spectroscopy (QEPAS) has demonstrated the capability to perform trace gas detection for environmental monitoring with excellent sensitivity and selectivity, also providing high sensor compactness and ruggedness. The QEPAS sensors exploit a quartz tuning fork as resonant piezoelectric transducer to convert the photoacoustic waves generated by the interaction among a laser source and the target molecule into an electric signal proportional to the target concentration. The tuning fork is typically coupled to millimetric resonator tubes in the so-called QEPAS spectrophone. In this project, two of the most relevant impurities in hydrogen samples will be investigated, namely carbon monoxide and ammonia. First, the spectral features of the two analytes to be targeted will be individuated and the response of the QEPAS spectrophone in the hydrogen matrix will be characterised. Then, two QEPAS sensors will be assembled, one for each analyte, identifying the best components with the aim of developing a shoe-size QEPAS box capable of standalone operation. Finally, the sensors will be tested and the performances in terms of detection limits will be assessed.

RESEARCH PROPOSAL
Sections (a) and (b) should not exceed 4 pages. References do not count towards the page limits.

Section a. State-of-the-art and objectives

The challenge of reducing the effects of global climate change must involve the path towards the reduction of carbon emission. In this perspective, a strong cut in the use of carbon-emitting energy sources (coal, oil, etc.) would lead to a global benefit. An important alternative to coal and fossil fuels is represented by hydrogen-related technologies, where hydrogen is used as an energy vector to power fuel cell systems and produce electrical energy starting from electrochemical oxidation of hydrogen. Different approaches have been investigated, such as polymer electrolyte fuel cells (PEFCs) and proton exchange membrane fuel cells (PEMFCs) [1-2]. Nevertheless, this technology is not competitive with traditional internal combustion engines due to the strict requirement of pure or purified hydrogen, whose preparation and storage costs are still high. The impurities are generated in the hydrogen production process, such as natural gas steam reforming in which the steam reacts with the natural gas in a set of reactions to produce mainly hydrogen, carbon dioxide, and carbon monoxide [3]. The need for high-purity hydrogen comes from the impact of impurities in the hydrogen matrix on the lifetime of the fuel cell systems, as even trace concentrations of contaminants may lead to relevant degradation of the fuel cell catalyst [4]. The list of damaging impurities in hydrogen includes: carbon monoxide, ammonia, carbon dioxide, sulphur compounds, and hydrocarbons. The analytes concentration in the hydrogen matrix is strongly dependent on the hydrogen production method; however these contaminants could significantly affect the fuel cell systems operations at concentration level in the range of part-per-million (ppm) and below. Therefore, it is crucial to adopt sensitive and accurate detection methods for online and offline detection of contaminants in hydrogen, to fulfil the requirements of international standards (ISO 14687:2019) [5].

Carbon monoxide (CO) represents a threat for hydrogen fuel cells due to its capability of binding to platinum (Pt) anodes, which are widely employed in fuel cells for hydrogen oxidation reactions and oxygen reduction reactions in acidic environments. For instance, a voltage loss of 85% was observed in a PEMFC cell following an exposure of 70 ppm for 6 hours [6], and the need for a constant concentration of CO below 10 ppm has been reported [7]. ISO 14687:2019 requires a CO threshold concentration of 0.2 ppm for grade D applications (fuel cells for road vehicles). Ammonia (NH_3) is a danger for fuel cell systems due to its reactive nature affecting the ion exchange capacity of the fuel cell leading to irreversible damage for high concentration or prolonged exposure [8]. ISO 14687:2019 requires a NH_3 threshold concentration of 0.1 ppm for grade D applications.

With the aim of monitoring the concentrations of hydrogen impurities different detection methods have been developed, for both offline and online monitoring. In the first case, the hydrogen mixtures are sampled and then delivered to a laboratory facility to be analysed. The detection and quantification of contaminants is performed employing instrumentation characterised by high sensitivity and selectivity, which in turn is usually expensive, requiring large footprint and qualified users. In this field, the golden standard is represented by gas chromatography coupled with different kinds of detectors as mass spectrometers, flame ionisation, and pulsed discharge helium ionisation detectors (PDHID) [9].

Conversely, online monitoring techniques allow the detection and quantification of hydrogen impurities on field and in real time. These methods represent a crucial tool to monitor contaminants' concentrations continuously, thus providing a prompt response in case of unexpected increase in impurities levels preventing malfunctioning of the apparatus. In this field, optical-based techniques may represent reliable solutions, being capable of sensitive detection for online monitoring. Sensors based on Fourier Transform InfraRed (FTIR) spectroscopy [10], cavity-enhanced Raman spectroscopy [11], and photoacoustic spectroscopy [12] for hydrogen contaminants detection have been demonstrated. However, the rising interest for hydrogen-related technologies has nowadays pushed new efforts in the development of sensitive, compact, rugged and reliable optical sensors for contaminants detection in hydrogen matrix.

In this project, we aim to develop a new sensing platform for two of the most relevant impurities in hydrogen matrices, i.e., CO and NH_3, based on quartz-enhanced photoacoustic spectroscopy (QEPAS). The latter represents a development of traditional photoacoustic spectroscopy, which has demonstrated higher sensitivity in a more compact sensing system [13]. Two different QEPAS sensors will be developed, each one housed inside a portable, shoe-size box equipped with the electronic boards and the gas line management system required to allow standalone operations. The goal of the project is to transfer the technologies developed for environmental monitoring in atmosphere (nitrogen matrix) to the detection of impurities in hydrogen, thus providing custom solutions ad hoc for this gaseous matrix. The QEPAS sensor will be validated in a laboratory environment, demonstrating their capabilities to match the requirements needed by the industry for fuel cell systems safety.

Section b. Methodology

Photonics sensors based on laser absorption spectroscopy (LAS) are of growing interest due to the recent development of powerful lasers tunable over large-wavelength ranges which permits unambiguous detection of numerous substances at low concentrations and in many cases even calibration free operation. They are considerably faster than non-photonic sensors (e.g. wet-chemical or chromatographic apparatus) and suffer from minimal drift. Photonics offers high specificity and sensitivity for real time in-situ measurement and allows the contactless simultaneous detection of many substances [14]. Photoacoustic spectroscopy follows different rules to absorption spectroscopy based on Lambert-Beer optical absorption, providing greater compactness and lower costs. The absorption of infrared photons in a gas sample results in the excitation of molecular energy levels whose energy is released as heat. The generated signal is proportional to the incident light intensity and, should this intensity be modulated, localised transient heating results. The medium responds creating acoustic (pressure) waves [15].

PAS sensors use a microphone to detect the pressure wave in a resonant acoustic gas cell. QEPAS replaces the microphone with a spectrophone, composed by a quartz-tuning fork (QTF) and a pair of millimetre-size resonator tubes, aligned on both sides of the QTF in a way that the laser beam can be focused between the QTF prongs while passing through both tubes [13]. A schematic of the QEPAS spectrophone is shown in Fig. 1a. When the laser beam is modulated at the resonance frequency of the QTF or a subharmonic, a standing wave vibrational pattern is created within the resonator tubes which deflects the two prongs in opposite directions, exciting the QTF in a piezoelectrically-active, anti-symmetrical flexural mode. Thus, an electrical signal proportional to the absorbing analyte concentration is generated. Thus, the technique is baseline free, greatly easing calibration with respect to absorption spectroscopy. The main strengths of QEPAS are: immunity to environmental acoustic noise (an issue for standard PAS systems), no requirement for optical detectors, compactness, capability to analyse small gas samples, wavelength-insensitivity, hyperspectrality, high accuracy and sensitivity, very large linear dynamic range (from few % to part per trillion range), long-time stability, low-cost and able to operate in real time and in situ [16].

From 2002, several QEPAS sensors in laboratory prototype system have been developed and more than 30 different analytes have been detected using a wide range of laser sources, from UV-visible (LEDs) to near- IR (diode) and mid-IR range (ICLs and QCLs), up to Terahertz range (QCLs). In most cases, ultimate detection limits in the part-per-billion range and down to part-per-trillion have been achieved, as shown in Fig. 1b [17].

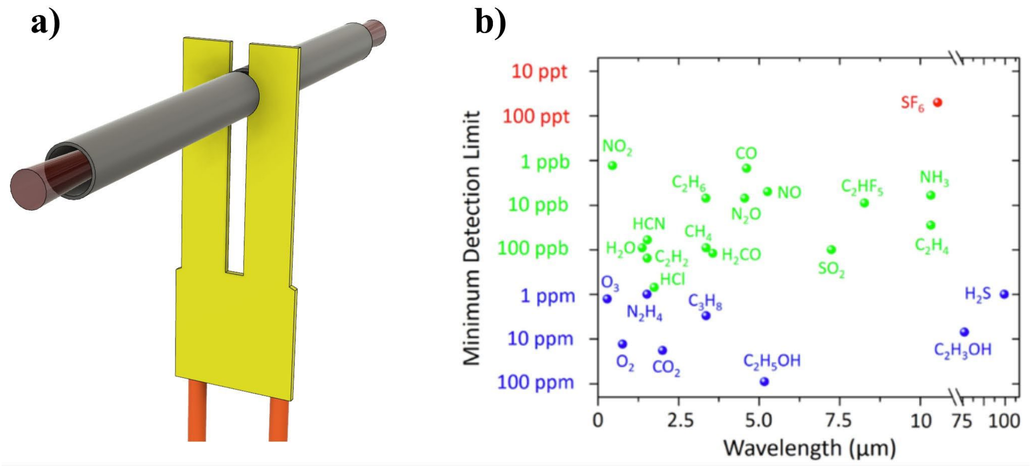

Figure 1. (a) Schematic of the QEPAS spectrophone consisting of a QTF (yellow) and a pair of millimetric resonator tubes (grey). The laser beam (transparent red) is focused through the tubes between the QTF prongs. (b) QEPAS detection limits for a selected list of gas species [17].

Prior to 2013, all the QEPAS sensors reported in the literature employed commercial standard quartz tuning forks (QTFs) (i.e. those used in watches) operating at the fundamental flexural resonance mode with a frequency of ~ 32.7 kHz, which size and geometry has been optimised for timing and not for sensing. Indeed, the prongs spacing (300 µm) and the micro-resonator tubes (internal diameter of 600 µm) are very narrow, making difficult the optical coupling with the laser source. Additionally, the operating frequency of 32.7 kHz is too high with respect to the energy relaxation processes occurring in the absorbing gas, resulting in low radiation-to-sound conversion efficiency. The development of custom QTF led to a key breakthrough represented by custom tuning forks with (i) reduced resonance frequency while keeping the quality factor high and (ii) enlarged prong spacing. Compared to the original design, the new tuning forks result in better sensing performance [18].

Hydrogen represents an excellent gaseous matrix for absorption spectroscopy, being mainly transparent in the IR region with the exception of some weak absorption lines around 2.12 µm [19]. Therefore, the optical detection can be performed by choosing suitable laser sources capable of matching spectral lines of target gases presenting no spectral interference with the absorption spectrum of other contaminants. In this way, the maximum spectroscopic signal will be found by means of a simple scan of the laser wavelength, thus avoiding the use for expensive reference cells but ensuring high selectivity to the measurements.

Moreover, from the perspective of photoacoustic waves generation, hydrogen would provide several benefits with respect to nitrogen or standard air. The change in the gas matrix leads to a change in the energy dissipation mechanism occurring in a vibrating prong, which is the damping by the surrounding fluid [20]. As a result, the matrix composition and its thermodynamic parameters affect the QTF quality factor. Since the QEPAS signal is proportional to the QTF quality factor, the ultimate sensor sensitivity will be in turn affected by the selected matrix [21]. For gas matrices composed by molecules with low molecular weight, such as hydrogen, an increase in the QTFs' quality factor is expected, thus resulting in an overall improvement of the detection performances. Nevertheless, to fully exploit the benefit arising from the hydrogen matrix, it is mandatory to use custom QEPAS spectrophone, with QTF geometry and resonator tubes size tailored to enhance the sensing performances.

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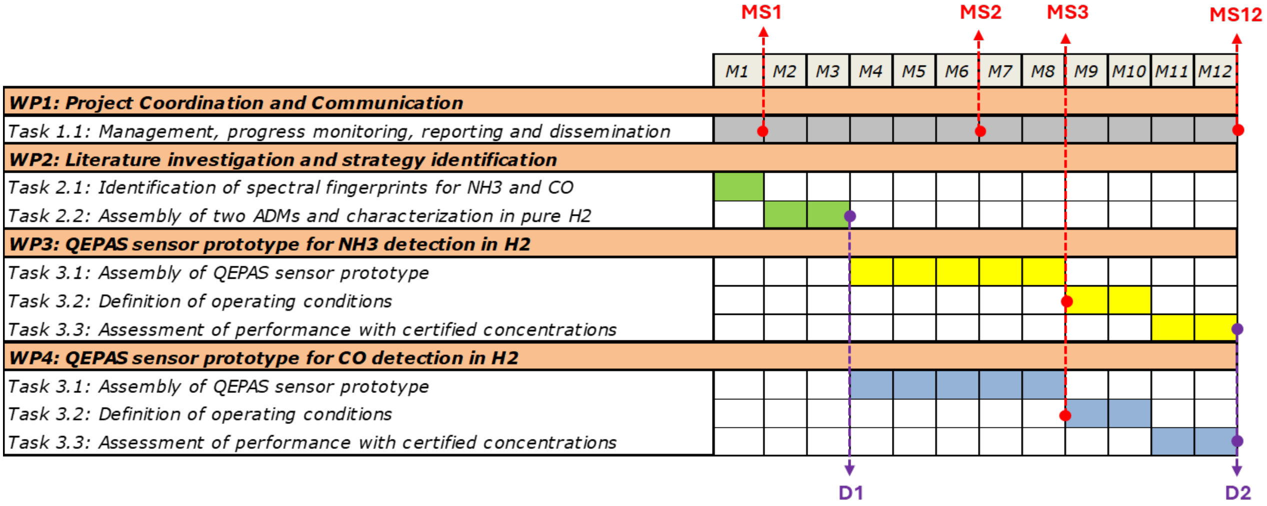
Section c. Available instrumentations and resources

The Physics Department of University of Bari contains the main equipment and tools to realise, test and validate Quartz-Enhanced Photoacoustic Sensing Systems for trace gas detection. This includes:

- a machine shop for the realisation of mechanical parts of vast complexity in three dimensions
- a 3D-printer for produce custom components with remarkable flexibility
- state-of-the-art facilities for design and realisation of acoustic detection modules
- testing workbenches for the characterization of optoacoustic transducers
- a clean room (80 m^2) equipped with mask aligner, e-beam evaporator, rapid thermal annealer and microscopes for realising electrical contacts on quartz crystals.
- several quantum cascade lasers and interband laser sources operating in the mid-infrared as well as several diode laser sources
- an optical spectrum analyzer for the characterization of laser sources
- an FT-IR spectrometer for gas molecules characterization
- several sets of THORLABS optics for the near- and mid-infrared spectral range
- gas management system, including over 20 gas flow lines for toxic/corrosive analytes, with flow and pressure controllers, vacuum systems, gas cabinets and cylinders with certified gas mixtures.

Section d. GANTT diagram

For scientific and technological effectiveness, the proposed project activities will be developed into 4 separate work packages (WPs), with clearly identified schedules (Gantt chart in Fig. 2)



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
WP1: Project Coordination and Communication												
Task 1.1: Management, progress monitoring, reporting and dissemination	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
WP2: Literature investigation and strategy identification												
Task 2.1: Identification of spectral fingerprints for NH3 and CO	🟩											
Task 2.2: Assembly of two ADMs and characterization in pure H2		🟩	🟩									
WP3: QEPAS sensor prototype for NH3 detection in H2												
Task 3.1: Assembly of QEPAS sensor prototype				🟨	🟨	🟨	🟨	🟨				
Task 3.2: Definition of operating conditions									🟨	🟨		
Task 3.3: Assessment of performance with certified concentrations											🟨	🟨
WP4: QEPAS sensor prototype for CO detection in H2												
Task 3.1: Assembly of QEPAS sensor prototype				🟦	🟦	🟦	🟦	🟦				
Task 3.2: Definition of operating conditions									🟦	🟦		
Task 3.3: Assessment of performance with certified concentrations											🟦	🟦

Figure 2. Gantt chart of the project.

Timing of the project is indicated in one-month packages in a Gantt Chart, broken down by work packages and tasks, including milestones and deliverables.

WP1 – Project Coordination and Communication

Task 1.1: Management, progress monitoring, reporting and dissemination (M1-M12)

The scientific activities will include: tracking progress towards scientific deliverables and milestones; making decisions on scientific activities in order to implement the overall strategy; drafting technical reports; creating a broad dissemination of communications.

WP2 – Literature investigation and strategy identification

Task 2.1: Identification of spectral fingerprints for NH3 and CO (M1)

This task will be devoted to the reconstruction of the infrared spectrum absorption of two selected analytes, namely CO and NH3, based on publicly available databases, including HITRAN, PNNL, Biorad, NIST, and SDBS. This literature research will be used as a guideline for the selection of the well-resolved features that can be used as fingerprints of related molecules, simplifying the identification process especially with interferers.

Task 2.2: Assembly of two ADMs and characterization in pure H2 (M2-M3)

Spectrophones composed by a custom quartz tuning fork (QTF) and a pair of resonator tubes will be assembled in aluminium Acoustic Detection Module (ADMs). The resonance properties of the spectrophone (the resonance frequency and its quality factor) as well as the noise level will be measured in pure hydrogen and compared with the performance in air.

WP3 – QEPAS sensor prototype for NH3 detection in H2

Task 3.1: Assembly of QEPAS sensor prototype (M4-M8)

In this task, the QEPAS sensor system for NH3 detection in H2 will be assembled starting from components, including the mechanical, optical and electrical parts. The laser source will be optically coupled with the ADM by means of a focusing lens. The prototype will include electronic control boards for controlling the laser source and a transimpedance amplifier for processing the QTF signal. The table-top QEPAS system will have full functionality, including gas management system, control and communications with a laptop.

Task 3.2: Definition of operating conditions (M9-M10)

The operating conditions will be assessed. The best operating pressure maximising the signal-to-noise ratio will be found. The wavelength modulation and second harmonic detection technique, together with an advanced data analysis and fitting models, will be implemented in order to retrieve the concentration measurement of the NH3 in the H2 matrix.

Task 3.3: Assessment of performance with certified concentrations (M11-M12)

The QEPAS sensor prototype will be tested in a laboratory environment using certified reference gas cylinders of NH3/H2 mixture and a gas mixing device. The test will be performed in a controlled environment, with specific parameters regulated, including temperature, humidity, pressure and gas flow. The performance of the sensor in terms of sensitivity, ultimate detection limit and long-term stability will be assessed.

WP4 – QEPAS sensor prototype for CO detection in H2

Task 4.1: Assembly of QEPAS sensor prototype (M4-M8)

In this task, the QEPAS sensor system for CO detection in H2 will be assembled starting from components, including the mechanical, optical and electrical parts. The laser source will be optically coupled with the ADM by means of a focusing lens. The prototype will include electronic control boards for controlling the laser source and a transimpedance amplifier for processing the QTF signal. The table-top QEPAS system will have full functionality, including gas management system, control and communications with a laptop.

Task 4.2: Definition of operating conditions (M9-M10)

The operating conditions will be assessed. The best operating pressure maximising the signal-to-noise ratio will be found. The wavelength modulation and second harmonic detection technique, together with an advanced data analysis and fitting models, will be implemented in order to retrieve the concentration measurement of the CO in the H2 matrix.

Task 4.3: Assessment of performance with certified concentrations (M11-M12)

The QEPAS sensor prototype will be tested in a laboratory environment using certified reference gas cylinders of CO/H2 mixture and a gas mixing device. The test will be performed in a controlled environment, with specific parameters regulated, including temperature, humidity, pressure and gas flow. The performance of the sensor in terms of sensitivity, ultimate detection limit and long-term stability will be assessed.

Section e. Milestones, Deliverables and KPI

The list of Milestones is reported in Table 1.

Table 1. List of Milestones

MS	Milestone Title	WP	Due	Means of Verification
MS1	Definition of strategy	1	M1	Report on dissemination plan and schedule of scientific activities
MS2	Mid-Term Project Status	1	M6	Report on mid-term progresses related to scientific activities and assessment of strategies for next activities
MS3	Assembly of two QEPAS sensors	3-4	M8	Report on the design and realisation of a QEPAS sensor prototype for NH3 detection in H2 and a QEPAS sensor prototype for CO detection in H2
MS4	Communication and dissemination reached	1	M12	Report on dissemination to the scientific community (open-access publications, scientific seminars and conferences) and to a wider public (social media, local and national press release)

The list of Deliverables is reported in Table 2.

Table 2. List of Deliverables

D	Deliverable Title	WP	Due	Type
D1	Report on laser characteristics and on performance of spectrophone in H2 environment	2	M3	Report

D2	A QEPAS sensor prototype for NH_3 detection in N_2 and a QEPAS sensor prototype for CO detection in N_2	3-4	M12	Two Demonstrators with datasheet/specification

Annexes: Curriculum vitae research team

Curriculum vitae PI

PERSONAL INFORMATION

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Date of birth:
Nationality:
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- **EDUCATION**

2022	PhD in Physics Physics Department, Università degli Studi di Bari “Aldo Moro”, Italy Supervisor: Prof. Vincenzo Spagnolo, Prof. Pietro Patimisco
2018	Master of Science in Physics Physics Department, Università degli Studi di Bari “Aldo Moro”, Italy

- **CURRENT POSITION(S)**

2023 –	RTD-A researcher Physics Department, Università degli Studi di Bari “Aldo Moro”, Italy

- **PREVIOUS POSITIONS**

2022 – 2023	Post-Doc Researcher (assegnista di ricerca) Physics Department, Università degli Studi di Bari “Aldo Moro”, Italy

- **FELLOWSHIPS AND AWARDS**

2022	Post-Doctoral Research Fellowship Spectroscopy Research and Development Group, THORLABS GmbH, Bergkirchen, Germany
2021	Best Presentation Award, International School of Quantum Electronics, 64th course, Progress in Photoacoustic and Photothermal Phenomena
2019	Visiting Researcher at Institute of Laser Spectroscopy in Shanxi University, Taiyuan, China, within the “Hundred Talents” project of the Chinese Academy of Science

- **SUPERVISION OF GRADUATE STUDENTS**

2023 –	n°1 PhD Students Interuniversity PhD course in Smart and Sustainable Industry, Technical University of Bari, Italy
2023 –	n°2 Master Students Master's degree in Physics, Physics Department, Università degli Studi di Bari, Italy

ORGANISATION OF SCIENTIFIC MEETINGS

2023	Organiser of CONFERENCE ON PHOTONICS FOR ADVANCED SPECTROSCOPY AND SENSING / Italy International Conference/ 150 participants / Italy https://www.c-pass.eu/

REVIEWING ACTIVITIES

2023–	Guest Editor of the Special Issue of "Sensors" journal, MDPI: "Photonics for Advanced Spectroscopy and Sensing" https://www.mdpi.com/journal/sensors/special_issues/9533LV9TQ9
2023 –	Review Editor of the section "Environmental Analytical Methods" of "Frontiers in Environmental Chemistry" journal, Frontiers In https://www.frontiersin.org/journals/environmentalchemistry/sections/environmental-analytical-methods/editors
2023 –	Topic Coordinator of the Special Issue of "Frontiers in Chemistry" journal, Frontiers In: "Recent Advances in Optical Sensing for Multi-Gas Detection" https://www.frontiersin.org/research-topics/56166/recentadvances-in-optical-sensing-for-multi-gas-detection)

MAJOR COLLABORATIONS

Lei Dong and Hongpeng Wu, *Development of optical sensors based on light-induced thermoelastic spectroscopy*, Shanxi University, State Key Laboratory of Quantum Optics and Quantum Optics Devices, Taiyuan, China
Reference Paper: https://doi.org/10.1063/5.0062415

T. Muller, *Multivariate analysis and digital twin modelling: alternative approaches to molecular relaxation in photoacoustic spectroscopy*, Regensburg University of Applied Sciences, Regensburg, Germany
Reference Paper: https://doi.org/10.1016/j.pacs.2023.100564

M. Gonzalez, *Hydrocarbons monitoring for natural gas analysis using optical spectroscopy*, Aramco Services Company, Aramco Research Center, Houston, United States
Reference Paper: https://doi.org/10.1016/j.pacs.2023.100448

R. Blanchard, *Study of optical sensors based on broadband infrared sources for multi-gas species detection*, Pendar Technologies, Cambridge, United States
Reference Paper: https://doi.org/10.1016/j.pacs.2019.100159

Q.J. Wang, *Development of QEPAS-based sensor box for simultaneous detection of contaminants in atmosphere,* School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore
Reference Paper: https://doi.org/10.3389/fenvc.2022.926233

Current grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current proposal*
-	-	-	-	-	-

Curriculum vitae CO-PI

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URL for website: http://polysense.poliba.it/index.php/pietro-patimisco/

EDUCATION

2013	PhD in Physics Physics Department, University of Bari, Italy PhD Supervisor: Prof. Gaetano Scamarcio
2009	Master’s degree in physics Physics Department, University of Bari, Italy

CURRENT POSITION

2023 –	Associate Professor (SSD FIS03) Physics Department, University of Bari, Italy

PREVIOUS POSITIONS

2020 – 2023	Assistant Professor (Ricercatore a Tempo Determinato-b) Physics Department, University of Bari, Italy
2018 – 2020	Assistant Professor (Ricercatore a Tempo Determinato-a) Technical University of Bari, Italy
2017 – 2018	Post-Doc Position Physics Department, University of Bari, Italy
2013 – 2016	Post-Doc Position Physics Department, University of Bari, Italy

FELLOWSHIP

2016 – 2017	Post-Doctoral Research Fellowship Laser Science Group, Electrical and Computer Engineering Department, Rice University, Houston, Texas

2018 – 2019	Visiting Researcher at Institute of Laser Spectroscopy in Shanxi University, Taiyuan, China, within the “Hundred Talents” project of the Chinese Academy of Science

SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS

2019 –	n°8 Master Students Master’s degree in physics, Physics Department, University of Bari, Italy
2020 –	n°4 PhD Students PhD School in Physics, Physics Department, University of Bari, Italy
2021 –	n°2 PhD Students Interuniversity PhD School in Industry 4.0, Technical University of Bari, Italy
2021 –	n°2 post-Docs Physics Department, University of Bari, Italy

ORGANISATION OF SCIENTIFIC MEETINGS

2023	Organiser and Member of the Technical Committee of CONFERENCE ON PHOTONICS FOR ADVANCED SPECTROSCOPY AND SENSING / Italy International Conference / 150 participants / Italy https://www.c-pass.eu/

INSTITUTIONAL RESPONSIBILITIES

2017 -	Member of the Technical Committee of Polysense Laboratory Technical University of Bari, Italy
2018 – 2020	Member of “Giunta del Dipartimento di Fisica” University of Bari, Italy
2019 – 2020	Member of “Consiglio della Scuola di Scienze e Tecnologia” University of Bari, Italy
2020 – 2023	Vice-Coordinator of the PhD Program Committee of the Interuniversity PhD School in Industry 4.0 Technical University of Bari, Italy
2023 –	Vice-Coordinator of the PhD Program Committee of PhD School in Physics University of Bari, Italy

PATENTS

2020 -	Chinese Patent n° 202010087714.6. Title “*A method and a device for improving the sensitivity of gas concentration detection of quartz enhanced photoacoustic spectrum*”. Inventors: H. Wu, L. Dong, Z. Shang, S. Li, V. Spagnolo, A. Sampaolo, P. Patimisco.

2022 -	Chinese Patent n° 112834430B. Title "*A device and method for gas detection based on acoustic pulse excitation of photoacoustic cell*". Inventors: H. Wu, L. Dong, T. Wei, W. Yinzho, V. Spagnolo, A. Sampaolo, P. Patimisco, M. Giglio.

REVIEWING ACTIVITIES

2018 –	Member of the Editorial Board of "Sensors" journal MDPI, https://www.mdpi.com/journal/sensors/editors
2019 – 2020	Guest Editor of the Special Issue of "Sensors" journal, MDPI: Optical Spectroscopy, Sensing, and Imaging from UV to THz Range https://www.mdpi.com/journal/sensors/special_issues/OSSITR
2022 – 2023	Guest Editor of the Special Issue of "Photoacoustic" journal, Elsevier: Photoacoustic spectroscopy for gas sensing: from theoretical modelling to applications https://www.sciencedirect.com/journal/photoacoustics/special-issue/107XM34RKBJ

MAJOR COLLABORATIONS

Simone Borri and Paolo de Natale, *Study and development of cavity-enhanced absorption spectroscopic techniques for highly sensitive and selective trace gas sensing*, Istituto Nazionale di Ottica (INO-CNR), Firenze, Italia.
Reference Paper: https://doi.org/10.1016/j.pacs.2022.100436

Lei Dong and Hongpeng Wu, *Development of optical sensors for real-time and in-situ monitoring of air*, Shanxi University, State Key Laboratory of Quantum Optics and Quantum Optics Devices, Taiyuan, China
Reference Paper: https://doi.org/10.1016/j.pacs.2024.100585

Yufei Ma, *Development of light-induced thermoelastic spectroscopy with custom quartz tuning fork*, National Key Laboratory of Science and Technology on Tunable Laser, Harbin Institute of Technology, Harbin 150001, China
Reference Paper: https://doi.org/10.1016/j.pacs.2022.100381

Frank Tittel, *Development of quartz-enhanced photoacoustic spectroscopy for sensing applications*, Rice University, Department of Electrical and Computer Engineering, Houston, TX, United States
Reference Paper: https://doi.org/10.1016/j.pacs.2023.100502

Y. Bidaux and J. Faist, *Study of wavelength modulation spectroscopy with quantum cascade laser sources*, Eidgenossische Technische Hochschule (ETH), Institute for Quantum Electronics, Zurich, Switzerland
Reference Paper: http://dx.doi.org/10.1364/OE.24.025943

R. Blanchard, *Study of optical sensors based on broadband infrared sources for multi-gas species detection*, Pendar Technologies, Cambridge, United States
Reference Paper: https://doi.org/10.1016/j.pacs.2019.100159

M. Deffenbaugh, *Development of optical sensors for oil/gas applications*, Aramco Services Company, Houston, TX, United States
Reference Paper: https://doi.org/10.1016/j.snb.2018.11.132

Current grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current proposal*
OPTAPHI	H2020-MSCA-ITN-2019	200 k€	2019 – to date	- Responsibility of commercialization - IP manager	Study of innovative spectroscopic techniques for gas sensing
PASSEPARTOUT	H2020-ICT-37-2020-101016956	630 k€	2020 – to date	- Local Unit Manager - WP Leader	Development of quartz-enhanced photoacoustic sensors for air pollutants detection
NQSTI2022	PNRR Extended Partnerships “National Quantum Science and Technology Institute”	870 k€	2022 – to date	- Task Leader	Development of quantum sensing technologies for gas sensing

AGRITECH2022	PNRR National Research Centre for Agricultural Technologies	80 k€	2022 – to date	- Task Leader	Development of quartz-enhanced photoacoustic sensors for agricultural monitoring applications
QUASIMODO	MUR Dipartimento di Eccellenza 2023-2027	200 k€	2023 – to date	- WP Leader	Quantum Sensing and Modeling for One-Health
SIMBA	PRIN PNRR 2022	50 k€	2023 – to date	- Local Unit Manager - WP Leader	Study of surface acoustic waves on piezoelectric substrates