In conjunction with **ICTON**, 24th International Conference on Transparent Optical Networks,
BARI, Italy, **July 14-18, 2024**
https://www.icton2024.fbk.eu/home

Scope of workshop: Microstructured Optical Fibers (MOFs) are among the most important forms of specialty fibers and their key property is the idea that, to a quite large extent, it is possible to tailor the basic optical properties of an optical fiber by modifying its geometrical transversal structure. The change may concern the disposal of air or glass defects within the fiber section, and, in particular, their position, size, shape, number and arrangement. This workshop intends to cover updated research within the topic of MOFs and subjects of interest include, but are not limited to highly nonlinear MOFs , hollow core optical fibers, MOF based active devices.

Technical Program Committee:

Chair: Walter Belardi, University of Parma, Italy

Members: Ole Bang, Danish Technical University, Denmark
Pavel Peterka, The Czech Academy of Sciences, Czech Republic
Jonathan Hu, Baylor University, USA
Azizur Rahman, City University of London, United Kingdom
Bishnu Pal, Ecole Centrale School of Engineering Mahindra University, India
Pier Sazio, University of Southampton, United Kingdom
Markus Schmidt, Friedrich Schiller University Jena, Germany
Peter Mosley, University of Bath, United Kingdom

Keynote speakers:

Johann Troles, University of Rennes, France
Chalcogenide microstructured optical fibers: fabrication and applications

Francesco Poletti, University of Southampton, United Kingdom
Hollow core fibres: the long and winding road from scientific tool to commercial product

Microstructured Optical Fibers Workshop 2024

DAY 0

18:30 – 20:00 → Welcome Reception at the *Politecnico di Bari*

DAY 1

15/07/2024 Mo.A.2 Plenary

10.00	**Johann TROLES**	Chalcogenide microstructured optical fibers: fabrication and applications

15/07/2024 Aula 7 Mo.B.4 MOF 1: Low loss hollow core fibers
Chair : Walter BELARDI

11.20	Walter BELARDI	MOF Opening
11.30	**Francesco POLETTI**	Hollow core fibres: the long and winding road from scientific tool to commercial product
12.00	Michael FROSZ	Non-invasive techniques for measuring the microstructure of hollow-core fibres during drawing
12.20	Luca VINCETTI	Hollow Core Inhibited Coupling Fibers: theoretical and real limits
12.40	Ali AL DHAYBY	Hollow-core fibers with reduced surface roughness for record losses and beam delivery in the UV domain

15/07/2024 Aula 7 Mo.C.4 MOF 2: Hollow core fibers for unconventional wavelengths range
Chair : Walter BELARDI

14.00	Qiang FU	Advances in Mid-Infrared Low-Loss Hollow-Core Anti-Resonant Fibers
14.20	Walter BELARDI	Designing and exploiting the properties of gas filled hollow core optical fibers
14.40	Kerrianne HARRINGTON	Anti-resonant hollow core fibres for UV guidance
15.00	Alessio STEFANI	Flexible hollow core waveguides for THz applications and conformal sensing

15/07/2024 Aula 7 Mo.D.4 MOF 3: Properties of hollow core fibers
Chair : Walter BELARDI

15.40	Rodrigo AMEZCUA CORREA	High energy laser transmission in hollow core fibers
16.00	Stephanos YEROLATSITIS	Controlling the transmission bandwidth of anti-resonant hollow-core fibers
16.20	Fei YU	Tailoring modal properties of photonic-bandgap hollow-core fibers
16.40	Federico MELLI	2D+1 and 3D Simulation Methods for Hollow Core Fibers Non-Idealities Analysis

18:00 – 19:30 → Guided tour in *Alberobello*

20:00 – 23:00 → Dinner at *La Chiusa di Chietri*

DAY 2

16/07/2024 Aula 7 Tu.A.4 MOF 4: Nonlinear and quantum phenomena in Microstructured Optical Fibers
Chair : Peter MOSLEY

08.30	David NOVOA	Harnessing Light Quanta with Fibre-Based Molecular Modulators
08.50	Peter MOSLEY	Microstructured fibre technologies for quantum networks
09.10	Lorenzo ROSA	Hollow-core fibers as quantum photon source platform
09.30	Jesper LAEGSGAARD	Power scaling of normal-dispersion continuum generation: Merging fiber and light structuring

16/07/2024 Aula 7 Tu.A.4 MOF 5: Postdeadline session
Chair : Peter MOSLEY

09.50	**Alexander DAVIS**	Tunable near-degenerate frequency conversion using doped photonic crystal fiber

16/07/2024 Aula 7 Tu.B.4 MOF 6: Microstructured optical fiber devices
Chair : Pier SAZIO

10.40	Laurent BIGOT	Some Recent Advances on Few-Mode Fibers and Multicore Fibers for Space-Division Multiplexing
11.00	Armando RICCIARDI	Active fibers: integration of miniaturized optoelectronic devices on optical fibers
11.20	Siddharth SIVANKUTTY	Ultra-thin endoscopes: two-photon imaging at the tip of a bare fiber with wavefront shaping
11.40	Pavel HONZATKO	Acoustic vibrations sensitivity of negative curvature hollow core optical fibres
12.00	Xuehao HU	Temperature measurement utilizing tilted Bragg gratings in solution-filled specialty optical fiber

16/07/2024 POSTER AREA Tu.B.4 MOF 7: Poster session

10.20 - 10.40 12.20 - 13.00	Dakun WU	Nanosecond pulse delivery at 1064 nm in a multimode antiresonant hollow core fibre
10.20 - 10.40 12.20 – 13.00	Xinyue ZHU	High Power Single Frequency Fiber Gas Raman Lasers
10.20 - 10.40 12.20 - 13.00	Si CHEN	In-situ background-free Raman probe using double-cladding anti-resonant hollow-core fibers

Session Chairs

Walter Belardi
University of Parma
(Italy)
Chair MOF 1-2-3

Peter Mosley
University of Bath
(United Kingdom)
Chair MOF 4-5

Pier Sazio
University of Southampton
(United Kingdom)
Chair MOF 6

Abstracts : DAY 1

MoA.2

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Chalcogenide microstructured optical fibers: fabrication and applications

Chalcogenide glasses are known for their large transparency in the mid-infrared and their high linear refractive index (>2). They also present a high non-linear coefficient (n2), 100 to 1000 times larger than for silica, depending on the composition. An original way to obtain fibers is to design microstructured optical fibers (MOFs). These fibers present unique optical properties thanks to the high degree of freedom in the design of their geometrical structure. Various chalcogenide MOFs were elaborated in order to associate their mid infrared transmission with the original MOF properties. Different glass compositions and designs have been achieved depending on the intended application. Indeed, chalcogenide MOFs might lead to new devices with unique optical properties in the mid-infrared domain, such as multimode or endlessly single-mode transmission of light, small or large mode area fibers, non-linear properties for wavelength conversion, or generation of supercontinuum sources. Different elaboration methods can enable the production of microstructured preforms, such as stack and draw, molding, extrusion, and also recently additive manufacturing. In the 1-12 µm window, single-mode fibers, polarization-maintaining fibers, and exposed core fibers have been realized for Gaussian beam propagation and sensor applications.

MoB.4.2

Francesco Poletti
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Hollow core fibres: the long and winding road from scientific tool to commercial product

Hollow core fibres have been conceived theoretically over a century ago and first demonstrated at the beginning of this millennium. For a couple of decades, their main impact has been mostly in the support of scientific experiments in academic labs around the world. In the last few years, thanks to substantial improvements in optical performance, they are beginning to carve themselves commercial opportunities in various markets, including that of optical communications. In this talk we will review the past challenges and hint at some of the future forthcoming opportunities.

MoB.4.3

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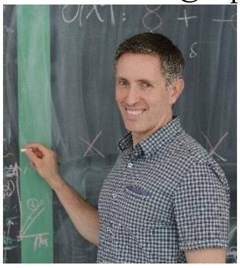

Non-invasive techniques for measuring the microstructure of hollow-core fibres during drawing

Microstructured hollow-core fibres are becoming increasingly important for both industry and research. However, the robustness of their fabrication is still far from the level of how standard telecom fibres are made. One key stumbling block is how to ensure that the desired microstructure is achieved without cutting and sampling the fibre. The talk will cover recent breakthroughs in measuring the microstructure non-invasively during drawing.

MoB.4.4

F. Melli[1], L. Rosa[1], K. Vasko[2,3], F. Benabid[2,3], and **Luca Vincetti[1]**
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Hollow Core Inhibited Coupling Fibers: theoretical and real limits

In this work we present theoretical and numerical tools and apply them for analyzing the main performance limits of Hollow Core Inhibited Coupling Fibers, highlighting the ultimate limits in ideal fibers and the current limits coming from non-idealities of real fibers.

MoB.4.5

Ali Al Dhaybi[1], Jonas Osorio[1], Frédéric Delahaye[2], Kostia Vasko[1,2], Foued Amrani[2], Gilles Tessier[3], Luca Vincetti[4], Benoit Debord[1,2], Frédéric Gérôme[1,2] and Fetah Benabid[1,2]
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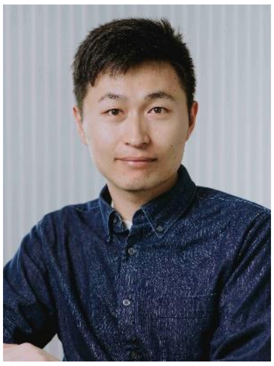
Hollow-core fibers with reduced surface roughness for record losses and beam delivery in the UV domain

We report a new generation of HCPCFs demonstrating ultralow loss in the short-wavelength domain by the use of new fabrication process. The process consists of applying a shear stress on the fiber silica core-surround surface. This approach allows a significant silica surface roughness reduction demonstrated by using a home-made picometer-resolution and high dynamic range profilometer. The surface quality improvement is further corroborated by record optical performances measured in the UV spectral range with losses between 50-10 dB/km in the wavelength range of 280-400 nm. As a demonstration of the interest of such fibers, UV laser beam delivery at specific industrial wavelengths including 257/266 nm and 343/355 nm are presented.

MoC.4.1



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Advances in Mid-Infrared Low-Loss Hollow-Core Anti-Resonant Fibers and Their Applications in Power Delivery

This presentation is an overview of the latest developments in mid-infrared hollow-core anti-resonant fibers, conducted by the Optoelectronics Research Centre (ORC) at the University of Southampton. These fibers are designed for low loss within the critical wavelength range of 3-6 μm. Leveraging these fibers, we have successfully demonstrated laser power delivery over distances reaching up to the hundred-meter scale. This breakthrough in fiber optics technology presents new opportunities for numerous applications including material processing, sensing, and biomedical devices.

MoC.4.2

Walter Belardi[1], William Wadsworth[2], Jonathan Knight[2], Piotr Jaworski[3], Karol Krzempek[3], Aymeric Pastre[4], Geraud Bouwmans[4], Laurent Bigot[4], Luca Vincetti[5], Lorenzo Rosa[5], Annamaria Cucinotta[1]
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Designing and exploiting the properties of gas filled hollow core optical fibers

Hollow core optical fibers can efficiently guide light in air, within an extended wavelength range. Their adoption as a passive means for optical transmission is of particular interest for short and long-haul optical communications.
However, also filling them with gases of various chemical compositions reveal to be advantageous for several applications. Firstly, this can be exploited for building novel gas-based fiber laser sources in spectral domains, or with properties, inaccessible by using conventional optical fibers. Secondly, the presence of even extremely low hazardous gas concentrations within the central core of these hollow fibers can be detected. This can be exploited by building compact hollow core fiber-based sensor devices, by using various forms of optical detection techniques. Finally, gas-based hollow core fibers could be also exploited in the field of quantum information.

MoC.4.3

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Anti-resonant hollow core fibres for UV guidance

We summarise our progress on fabricating hollow core fibres with <250 nm silica wall structures needed for UV guidance, with particular focus on deep UV guidance (<280 nm). Through improvements in our fabrication process, we can produce thin glass walls in tubular hollow core fibres from one cane stage stack-and-draw methods that can have high yield (1-5 km). We have produced both single-mode and multi-mode hollow core fibres that guide most of the UV wavelength range, down to the shortest wavelength guidance achievable in air.

MoC.4.4

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Flexible hollow core waveguides for THz applications and conformal sensing

Investigation of elastomer-like materials for optical fibers enables applications where large deformations are needed, as well as applications where the desired deformation can be obtained with small forces. Such materials are generally not the material of choice for waveguides as they have a low optical transparency. This issue can be overcome by using hollow core structures.
In this paper we present our work in the realization of various novel THz waveguides that are bendable despite their centimeter-scale cross section. We also show how scaled down waveguides of such a flexible material can used as wearable conformal sensors for physiological parameters such as gait, respiration rate and pulse.

MoD.4.1

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High energy laser transmission in hollow core fibers

Hollow-core fibers, which guide light in air, have opened up exciting possibilities for high-energy and high-power laser delivery, thanks to their exceptionally low nonlinearities and high damage thresholds. Recently, we have shown that narrow linewidth multi-kW laser powers can be efficiently transported through these fibers over long distances without detrimental nonlinearities.
Novel hollow core fibers will lead to a new generation of laser beam delivery systems with applications in precision machining, nonlinear science, and directed energy.

MoD.4.2

S. Yerolatsitis[a,b], J. Keohane[c], S. Vinta[c], R. Mears[c], K. Harrington[c], R. J. A. Francis-Jones[c,d], K. Kalli[a], K. Rusimova[c]
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Controlling the transmission bandwidth of anti-resonant hollow-core fibers

We have developed an innovative anti-resonant hollow-core fiber design with capillaries of alternating thicknesses. This unique arrangement, featuring six silica capillaries of two different thicknesses, effectively narrows the transmission bandwidth while maintaining low attenuation. Validated through simulations, our design marks a significant step in developing the first in-line hollow-core bandwidth filter fiber. We envision that our novel fiber design has a variety of applications, such as suppressing non-linear effects and developing wavelength-selective components for future conventional and quantum communication networks.

MoD.4.3

Chaochao Shen[1,] **Fei Yu**[1,2] and Jonathan Knight[3]
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Tailoring modal properties of photonic-bandgap hollow-core fibers

Surface modes (SMs) are localized modes of photonic bandgap hollow-core fiber (PBG-HCF) existing in the fine struct of core wall. SMs are often regarded hazardous which give rise higher loss by coupling with the air modes of PBG-HCF. In this paper, we report the use of SM in the tailoring of modal properties of PBG-HCF with relatively low loss. Owing to the anti-crossing between air modes and SMs, up to 2.6×10^{-3} group birefringence is measured in a transmission window from 1472 nm to 1560 nm where the minimum attenuation is 39 dB/km. A large range of thermal group delay of PBG-HCF is demonstrated possible to be tuned from -120 ppm/K to 120 ppm/K by proper design of SM in theory. New designs of PBG-HCFs with low modal losses are also reported in this paper.

MoD.4.4

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2D+1 and 3D Simulation Methods for Hollow Core Fibers Non-Idealities Analysis

We propose three numerical approaches for the analysis of Hollow Core fibers non-idealities along fiber propagation direction. The first two are 2D+1 approaches and relies on the Coupled Mode Theory and the Mode Matching Method. While the third is a full 3D method since it relies on a 3D finite element method simulation.

Abstracts: DAY 2

Tu.A.4.1

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Harnessing Light Quanta with Fibre-based Molecular Modulators

The manipulation of the frequency content of arbitrary optical signals is of paramount importance in many disparate fields. This is usually achieved using nonlinear optical effects in bulk media such as crystals or gas cells, which restricts the degree of applicability of these techniques due to limitations in e.g. transparency, dispersion, nonlinearity strength and damage threshold. As an alternative to these common free-space arrangements, we will present a universal class of optical modulators based on hydrogen-filled hollow anti-resonant fibres with an unprecedented operational range from the ultraviolet to the THz, and capable of handling both classical signals with large photon numbers, as well as quantum light states down to the single-photon limit. The overall performance of these fibre-based molecular modulators can be conveniently scaled through certain characteristic lengths, which makes them versatile means of broadband frequency translation under different conditions.

Tu.A.4.2

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Microstructured fibre technologies for quantum networks

Microstructured fibre has the capability to address the challenges that exist in scaling up quantum networks for secure communications and computing. We present recent progress towards challenges including enhancing the performance of heralded single-photon sources, building frequency interconnects to link quantum network nodes, and developing fibre-integrated quantum memories.
We have demonstrated that frequency conversion by Bragg-scattering four-wave mixing (BS-FWM), when implemented in photonic crystal fibre (PCF), can create universal interfaces capable of linking quantum network nodes operating at different wavelengths to the telecoms C-band. We discuss the extension of BS-FWM interfaces to bandwidth conversion, both to enable more flexible interfaces and to generate narrowband single photons that can couple to atomic or solid-state systems.
Quantum memories capable of storing and retrieving single photons can be used both to mitigate the probabilistic nature of heralded single photon sources by multiplexing and also to synchronise gate operations in quantum processors based on linear optics. For both these applications, fibre integration is essential. We present progress towards rubidium vapour quantum memories in fully integrated hollow-core fibre (HCF) modules. In particular, we discuss the translation of low-loss single-mode fibre to HCF interfaces to the rubidium memory operating wavelengths around 780nm.

Tu.A.4.3

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Hollow-core fibers as quantum photon source platform

We present developments on platforms for quantum photon sources in gases using hollow-core inhibited-coupling microstructured optical fibers, by applying innovative hollow-core fiber modelling and experimental techniques.

Tu.A.4.4

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Power scaling of normal-dispersion continuum generation: Merging fiber and light structuring

The use of higher-order modes (HOMs) is emerging as a new route to scale the core size, and thereby operational power levels for nonlinear processes, while retaining desired dispersion properties. The peculiar guidance properties of microstructured optical fibers (MOFs) imply distinct advantages for HOM-based devices in terms of limiting mode competition, and extending the useful spectral guidance window. This contribution shows how combined tailoring of MOF structures and field profiles can lead to order-of-magnitude gains in the power levels of all-normal supercontinuum generation.

Tu.A.4.5

Leah R Murphy[1], Mateusz J Olszewski[1], Petros Androvitsaneas[1,2], Will AM Smith[1], Anthony Bennett[2], Peter J Mosley[1] , and **Alex O C Davis**[1]
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Tunable near-degenerate frequency conversion using doped photonic crystal fiber

Future quantum communication networks will rely on the ability to coherently transfer quantum information between different wavelength bands. Coherent frequency conversion in optical fibre by Bragg-scattering four-wave mixing is a promising route to achieving this, but requires fibres with precise dispersion control and broadband transmission at signal, target and pump wavelengths. Here we introduce a photonic crystal fibre with a germania-doped core, for which the group velocities at 1550nm and 920 nm are approximately matched, with good optical guidance even at long wavelengths. With low chromatic walk-off, large lengths of this fibre can be used to achieve frequency conversion between two wavelengths several nanometers apart in the GaAs quantum dot emission band. We demonstrate this with up to 78% internal conversion efficiency by pumping with two nearby C-band wavelengths. By cascading this interaction, we also show the generation of a frequency comb. We further demonstrate the potential of this fibre for downconversion between the GaAs dot band and telecoms C-band.

Tu.B.4.1

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Some Recent Advances on Few-Mode Fibers and Multicore Fibers for Space-Division Multiplexing

In this article, various research studies focusing on the evaluation of optical fiber designs and optical components compatible with spatial multiplexing of data for future fiber networks are presented. Whatever the approach considered, mastering the coupling between spatial channels is crucial. We will hence concentrate our presentation on the efforts carried out in this direction in the case of few-mode fibers (FMF), and particularly the works dedicated to the understanding of the link between mode coupling and light scattering mechanisms. Additional work on optical amplification in specialty erbium-doped few-mode fibers (FM-EDF) and multicore fibers (MCF) will also be reported.

Tu.B.4.2

Armando Ricciardi

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Active fibers: integration of miniaturized optoelectronic devices on optical fibers

The new 'Optoelectronics on Fiber' technology envisions novel fiber based active platforms combining the unique characteristics of the optical fibers with miniaturized advanced optoelectronic chips. Many reliable chip-to-fiber integration procedures have been recently proposed, giving rise to actively controllable multifunctional all-fiber devices with emission, detection, modulation, and sensing capabilities integrated in a single unit. The possibility to squeeze the entire optical interrogation setup (source, fiber, detector) into a single unit, with compact footprint, represents a technological and scientific breakthrough in many fields ranging from IoT up to biomedical technologies, that are currently limited by bulky interrogation systems.

Tu.B.4.3

Siddharth Sivankutty

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Ultra-thin endoscopes: two-photon imaging at the tip of a bare fiber with wavefront shaping

In this presentation, we will explore the utilization of specialty multi-core fibers combined with wavefront shaping to enable two-photon imaging using femtosecond pulses. Specifically, we will emphasize the optimization of both the design and the post-processing of these multi-core fibers to achieve a compact footprint (200 microns), efficient power delivery, and resilience to mechanical perturbations.

Tu.B.4.4

Pavel Honzatko, Andrei Borodkin, Yauhen Baravets, Ondrej Moravec
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Acoustic vibrations sensitivity of negative curvature hollow core optical fibres

We report on various aspects of interaction of acoustic waves withlight guided in negative curvature hollow core fibres. Backscatteringin these fibres is significantly suppressed thus greatly reducing a potential to exploit them for distributed acoustic sensing. In transmission, on contrary, their sensitivity to acoustic waves might even exceed sensitivity of conventional fibres. Implications and potential applications in sensing and measurement will be discussed.

Tu.B.4.5

Yang Liu[1], Hang Qu[1], Christophe Caucheteur[2], and **Xuehao Hu**[2]
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Temperature measurement utilizing tilted Bragg gratings in solution-filled specialty optical fiber

In this work, we propose a tilted fiber Bragg grating (TFBG) sensor for temperature measurements. The grating is inscribed using a femtosecond laser and the line-by-line (LbL) direct writing technique in the central core of a specialty optical fiber. The channel filled with glycerol aqueous solution beside the central core significantly improves the temperature sensitivity of the TFBG cladding modes due to its high thermo-optic coefficient (TOC). We show that the temperature sensitivity of the core mode is 9.59 pm/°C, while the counterparts of the cladding modes reach up to –29.45 pm/°C in the range of 20 - 40 °C.