Phosphate glass optical fibers for applications in sensing and biomedicine

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Friday, 13 October

Hall A	
8.30	**Hollow Core Fibres** Chair: Liang Dong
8.30-9.15	**Plenary 3 - Jonanthan Knight** **"What's the use of hollow core fibres?"**
9.15-9.35	**"Advances in Hollow Core Photonic Crystal Fiber Fabrication"** **Natalie Wheeler, John Hayes, Thomas Bradley, Yong Chen, Seyed Reza Sandoghchi, Marcelo Gouveia, Mubassira Nawazuddin, Eric Numkam, Gregory Jasion, Seyed Mousavi, Marco Petrovich, Francesco Poletti, David Richardson - Invited Paper (80)**
9.35-9.55	**"3D-printed Hollow Core OmniGuide Bragg Fibres for Mid-IR Transmission"** **Wanvisa Talataisong, Rand Ismaeel, Thiago Henrique Rosales Marques, Mohammed A. Mousavi, Martynas Beresna, Marcelo Gouveia, Seyed-Reza Sandoghchi, Andrei Donko, Timothy Lee, Cristiano M. B. Cordeiro, Gilberto Brambilla - Invited Paper (96)**
9.55-10.10	"Special Aspects of Revolver Hollow-Core Fiber Technology" Alexey Kosolapov, Alexander Biriukov, Andrey Pryamikov, Igor Bufetov - Paper (32)
10.10-10.25	"Demonstration of a Wide Bandwidth, Low Loss Hollow Core Photonic Bandgap Fiber in the 1.55 µm Wavelength Region" Y. Chen, E. Numkam Fokoua, T.D. Bradley, J.R. Hayes, S.R. Sandoghchi, N.V. Wheeler, G.T. Jasion, F. Poletti, M.N. Petrovich, D.J. Richardson- Paper (89)
10.25-10.55	**Coffee Break & Exhibit**
10.55	**Novel Materials and Methods** Chair: John Ballato
10.55-11.15	**"Phosphate glass optical fibers for applications in sensing and biomedicine"** **Daniel Milanese, Nadia Giovanna Boetti, Diego Pugliese, Edoardo Ceci-Ginistrelli, Davide Janner, Joris Lousteau - Invited Paper (81)**
11.15-11.30	"Highly deformable optical fibers made of polyurethane: OAM generation, tunable metamaterials and sensors" Alessio Stefani, Richard Lwin, Simon C. Fleming - Paper (4)
11.30-11.45	"Developing Multilayered Core Doped Silica Fiber for Enhanced Second Harmonic Generation (SHG)" Salah Abdullah Aljamimi, Younes Messaddeq, Jacques Albert, Christopher Smelser, Nicolas Grégoire, Steeve Morency, Hamed Jafferi, Tahseen Haque - Paper (54)
11.45	**Fibre Lasers and Amplifiers** Chair: Bishnu Pal
11.45-12.05	**"Random fiber lasers and applications"** **Yun-Jiang Rao - Invited Paper (99)**

Phosphate glass optical fibers for applications in sensing and biomedicine

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Abstract: Remote sensing and biomedicine require specifications and performance that are met by phosphate glass optical fibers. We report on our main achievements to date and provide insight into new functionalities.

OCIS codes: (160.2750) Glass and other amorphous materials; (160.2290) Fiber materials; (060.2280) Fiber design and fabrication; (160.1435) Biomaterials.

1. Introduction

Phosphate glasses are inorganic transparent materials that have recently attracted great interest because of their properties such as: easy manufacturing and handling, the ability to incorporate high amounts of rare-earth ions (10 times more than silica), large glass formation region, good thermal and chemical properties, significant mechanical strength and low nonlinear refractive index [1, 2].

Even though silica glass possesses outstanding thermal and mechanical properties, making it the material of choice for the development of optical fiber components, there are some applications where phosphate glass outperform silica. One example consists in the development of high peak power optical amplifiers, where fiber length reduction is paramount to minimize non-linear effects. Indeed, the use of highly doped rare-earth phosphate based optical fiber amplifiers allows attaining compact devices, which can be easily integrated with commercial silica fiber based components [3]. Main application fields of those components are interesting, e.g. for LIDARs and ranging.

A different application field is biomedicine, where there is a need for optical fibers which can be completely degraded in biological fluids. Such fibers could be implanted and employed for short- medium term therapy and diagnosis, thanks to their ability to be dissolved by aqueous media in a way controllable by the glass composition.

Here, we report on the latest advances in design and fabrication of phosphate glasses and optical fibers for compact optical amplifiers operating in the near infrared wavelength region, and for biomedical applications.

2. Double-cladding optical fibers for eye-safe power amplifiers

Double-cladding phosphate optical fibers were developed by preform drawing. The rod-in-tube technique was used to fabricate the preforms. The core rod was obtained by casting the molten glass into a cylindrical mold. The first and second cladding glass tubes, instead, were manufactured by exploring two different routes: rotational casting and extrusion. In the first case the procedure is quick and provides high quality tubes. However, the process is limited in terms of possible shapes and the range of achievable wall thickness. Extrusion, on the contrary, requires longer processing and optimization timescales, but allows for obtaining non-cylindrical shapes and asymmetric components, being limited only by the die designer's experience. An example of an extruded preform tube is reported in Fig. 1. Thanks to a careful engineering of the compositions, numerical apertures as low as 0.06 were obtained between the core and the first cladding, while 0.40 between the first and the second cladding could be reached by keeping the thermal properties similar. Er^{3+} was the emitter ion selected for eye-safe wavelength operation at 1550 nm, in combination with the sensitizer ion Yb^{3+}.

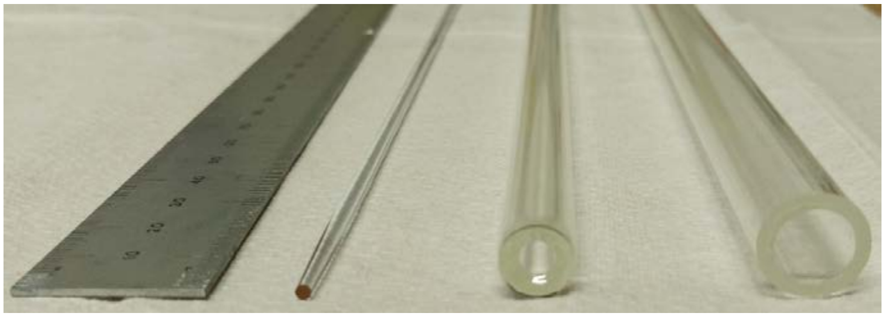

Fig. 1. Phosphate glass preforms obtained by extrusion: a core rod and two cladding tubes.

Multiple steps were required to obtain the desired fiber configuration and the final optical fiber drawing was carried out using an in-house built drawing tower operating at a speed of 5 m/min. The diameters obtained ranged from 125 μm up to 1 mm. An attenuation loss value down to 2 dB/m was measured at the wavelength of 1300 nm, and the optical gain of the fibers was also measured by cladding pumping in free space with a laser diode at 976 nm, obtaining a value of 2.3 dB/cm [4]. Recent activities have also led to the development of Yb-only fibers for the fabrication of short pulsed optical amplifiers for materials processing.

3. Resorbable optical fibers for biomedicine

biomedical applications, an added value can be represented by the possibility of avoiding removal by surgery if the material can be reabsorbed by the human body. The benefit is evident for applications like: endoscopy, in-vivo diagnostics, biomedical sensing and photothermal or photodynamic therapies.

To this aim biocompatible, biodegradable and UV transparent phosphate glasses were recently developed and drawn into multimode and single-mode optical fibers [5]. The fabrication procedure, described in the previous paragraph, was applied to a new formulation containing water soluble components: P_2O_5, CaO, MgO, Na_2O and SiO_2.

Degradation in biological fluids, photosensitivity [6] and testing for diffuse optics diagnostics were investigated for these fibers. The dissolution rate could be varied significantly by changing the glass composition, and mechanical tests were carried out to demonstrate their reliability [7].

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5. References

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