# Multimaterial bioresorbable optical fibers for theranostics

*Original*

Multimaterial bioresorbable optical fibers for theranostics / Milanese, Daniel; Pugliese, Diego; Boetti, Nadia G.; Pissadakis, Stavros; Konstantaki, Mary; Peterka, Pavel; Di Sieno, Laura; Gallichi-Nottiani, Duccio; Lousteau, Joris; Janner, Davide. - ELETTRONICO. - 11075:(2019), pp. 1-3. (Intervento presentato al convegno European Conference on Biomedical Optics 2019 (ECBO 2019) tenutosi a Munich, Germany nel 23-27 Giugno 2019) [10.1117/12.2527679].

*Publisher:*
SPIE

*Published*
DOI:10.1117/12.2527679

# Multimaterial bioresorbable optical fibers for theranostics

Daniel Milanese, Diego Pugliese, Nadia G. Boetti, Stavros Pissadakis, Maria Konstantaki, et al.

Daniel Milanese, Diego Pugliese, Nadia G. Boetti, Stavros Pissadakis, Maria Konstantaki, Pavel Peterka, Laura Di Sieno, Duccio Gallichi-Nottiani, Joris Lousteau, Davide Janner, "Multimaterial bioresorbable optical fibers for theranostics," Proc. SPIE 11075, Novel Biophotonics Techniques and Applications V, 110750S (22 July 2019); doi: 10.1117/12.2527679

Event: European Conferences on Biomedical Optics, 2019, Munich, Germany

# Multimaterial bioresorbable optical fibers for theranostics

Daniel Milanese*[a], Diego Pugliese[a], Nadia G. Boetti[b], Stavros Pissadakis[c], Maria Konstantaki[c], Pavel Peterka[d], Laura Di Sieno[e], Duccio Gallichi-Nottiani[b], Joris Lousteau[f], Davide Janner[a]
[a]Dept. of Applied Science and Technology and RU INSTM, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, Italy, 10129; [b]Links Foundation, Via P. C. Boggio 61, 10138, Torino, Italy; [c]Institute of Electronic Structure and Laser, FORTH, 100 N. Plastira Street, Heraklion, Crete, Greece, 70013; [d]Czech Academy of Sciences, Institute of Photonics and Electronics, Chaberská 57, Prague, Czech Republic, 18251; [e]Dept. of Physics, Politecnico di Milano, P.za Leonardo da Vinci 32, Milano, Italy, 20131; [f]Dept. of Chemistry, Materials and Chemical Engineering, Politecnico di Milano, Via Mancinelli 7, Milano, Italy, 20131.

## ABSTRACT

The design, fabrication and characterization of phosphate based bioresorbable optical fibers is reported. Applications in diffuse optics, pH sensing and temperature sensing have been demonstrated paving the way to the use for a new generation of implantable and degradable devices for theranostics.

**Keywords:** phosphate glass, optical fibers, bioresorbable, diffuse optical spectroscopy, pH sensors, fiber Bragg gratings.

## INTRODUCTION

Optical fibers have been widely employed for biomedical applications, thanks to their high flexibility and small size, enabling minimally invasive diagnosis and treatment of diseases [1]. Traditionally, silica fibers have been mainly used given their availability and the presence of related components and interconnects from the telecom technologies. These fibers are biocompatible and robust if properly packaged, e.g. as in endoscopes, although their stiffness and mechanical characteristics make them potentially very harmful for their use in catheters for example thus limiting their use and diffusion in the medical practice. Recently, a new generation of optical fibers has been developed to be resorbable, showing the ability to dissolve inside body fluids once their "operating life" has ended without the need of being explanted [2]. To this aim, inorganic glasses provide the best combination in terms of mechanical properties, optical transparency and fabrication scalability. Phosphate glasses can be engineered to provide custom dissolution rates and can be obtained both as solid or hollow fiber configurations [3,4].

We report on the design, fabrication and characterization of bioresorbable optical fibers and their suitability to provide a multifunctional device able to guide light and deliver chemicals, e.g. drugs and/or natural substances. A specific demonstration regards the possibility of their use as temperature sensors by means of UV-laser written fiber Bragg gratings.

## EXPERIMENTAL

### Glass and optical fiber fabrication and characterization

The bioresorbable glasses were designed with phosphorous oxide as glass former, while calcium, magnesium and sodium oxides were utilized as glass modifiers. All glasses were fabricated starting from powder chemicals with purity of at least 99+%, which were mixed and then molten in a crucible inside a chamber furnace at the temperature of 1400 °C for 1 h. Then the glass is cast into a preheated brass mold followed by annealing at $T_g$ for 3 h.

The core-cladding preforms were fabricated by the rod-in-tube technique, with the core obtained by casting the molten glass into a 4 mm diameter rod that fitted into a tube obtained by rotational casting at a rotation speed of 3000 rpm. A core/cladding rod of 4 mm diameter was then obtained by a second stretching and fit into a second tube identical to the

*daniel.milanese@polito.it; phone +390110904707; fax +390110904624; maps-polito.com

Novel Biophotonics Techniques and Applications V, edited by Arjen Amelink, Seemantini K. Nadkarni, Proc. of SPIE-OSA Vol. 11075, 110750S · © 2019 SPIE-OSA · CCC code: 1605-7422/19/$21 · doi: 10.1117/12.2527679

first one. The so obtained final preform was finally drawn into an optical fiber. The fabricated optical fibers were characterized by optical microscopy to assess the geometry and the quality of the core-cladding interface. Optical loss was measured at the wavelength of 1300 nm by the cut-back technique. Dissolutions tests of single material fibers were performed in Phosphate Buffered Saline solution (PBS, pH = 7.4) at a temperature of 37 °C.

### Applications

To assess the broad extent in which the bioresorbable fibers can be employed in biomedical devices, we tested them in three different applications spanning very different scenarios of potential interest for biomedical optics. The experiments were realized for the following applications: diffuse optics, fiber Bragg grating (FBG) as a temperature sensor, and pH sensor. Diffuse optics experiments were carried out using a pulsed laser source operating in the near IR wavelength region, using a multimode bioresorbable fiber for light injection and collecting the light pulses. A Single-Photon Avalanche Diode (SPAD) was employed as a detector and a Time-Correlated Single-Photon Counting (TCSPC) board was also employed. Experiments were carried out on phantoms and on chicken breast sample. A single mode fiber was employed to demonstrate the use of the fiber as pH sensor. The fiber was coated with a fluorescent pH sensitive dye which emits at the wavelength of 510 nm while excited in the blue region. FBGs were inscribed by means of the phase mask technique using an ArF excimer laser at the wavelength of 193 nm with pulse widths of 10 ns and their dissolution rates were tested.

## RESULTS

Single material and core/cladding optical fibers were successfully fabricated, both in multimode and single mode configurations. Table 1 reports the specifications of the single mode fiber.

Table 1. Single mode fiber specifications.

| Parameter | Value |
|---|---|
| Core diameter | 15 µm |
| Cladding diameter | 120 µm |
| Loss at 1300 nm | 2 dB/m |
| Loss at 633 nm | 5 dB/m |
| Numerical Aperture | 0.08 |

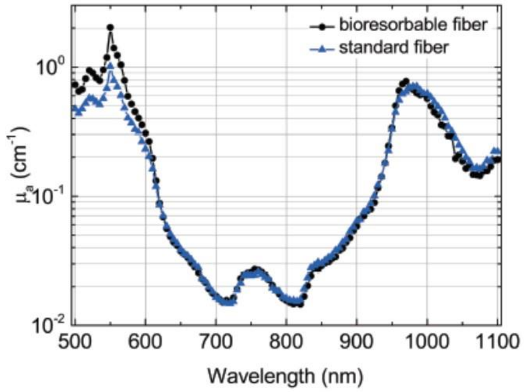

Figure 1. Absorption spectra of chicken breast using conventional (triangles) and bioresorbable fiber (circles).

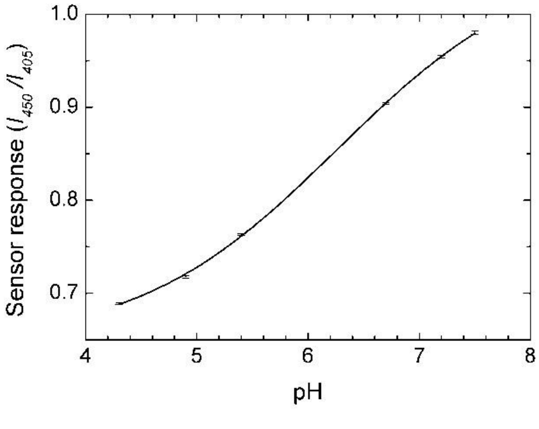

Figure 2. Optical fiber pH sensor response in the wavelength range between 5 and 7 (fitted by Boltzmann's equation).

The diffuse optics experiment led to the demonstration of the aptness of this fiber to measure both absorbed and scattered light in phantoms and chicken breast. On this last tissue, a full spectrum was recorded, as reported in Figure 1.

The pH sensor using the bioresorbable fiber was able to successfully measure pH values between 5 and 7 by measuring the fluorescence response of the emission intensities recorded by exciting the sample at the wavelengths of 405 and 450 nm (Figure 2).

Finally, the use of the UV-excimer laser allowed fabricating standard and tilted FBGs, and it was shown that the irradiated areas were subjected to accelerated dissolution in PBS. Figure 3 shows the time evolution of the FBG inscription using pulse energies of 108 mJ/cm$^2$ and a repetition rate of 10 Hz.

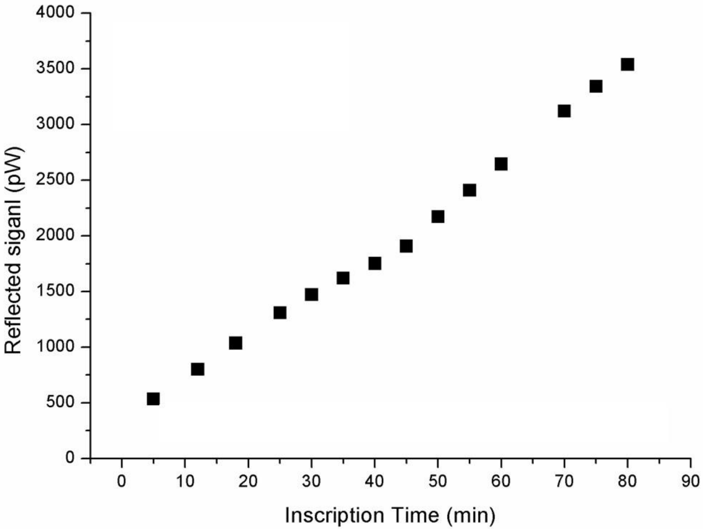

Figure 3. Time evolution of a fiber Bragg grating inscribed with an energy density of 108 mJ/cm$^2$ and a repetition rate of 10 Hz.

# ACKNOWLEDGMENTS

The authors wish to acknowledge the Interdepartmental Centre PhotoNext of Politecnico di Torino and the COST Action MP1401 for supporting this activity.

# REFERENCES

[1] Carmo, J., Ribeiro, J., “Optical Fibers on Medical Instrumentation: A Review”, International Journal of Biomedical and Clinical Engineering, 2(2), 1-14 (2013).
[2] Nazempour, R., Zhang, Q., Fu, R., Sheng, X., “Biocompatible and Implantable Optical Fibers and Waveguides for Biomedicine,” Materials 11(8), 1283 (2018).
[3] Ceci-Ginistrelli, E., Pugliese, D., Boetti, N.G., Novajra, G., Ambrosone, A., Lousteau, J., Vitale-Brovarone, C., Abrate, S., Milanese, D., “Novel biocompatible and resorbable UV transparent phosphate glass based optical fiber,” Opt. Mat. Expr. 6 (6), 2040-2051 (2016).
[4] Ceci-Ginistrelli, E., Pontremoli, C., Pugliese, D., Barbero, N., Boetti, N.G., Barolo, C., Visentin, S., Milanese, D., “Drug release kinetics from biodegradable UV-transparent hollow calcium-phosphate glass fibers,” Mater. Lett. 191, 116-118 (2017).