

Biodegradable, double-core, porous optical fiber.

CLEO 2006, postdeadline paper CPDB5

Alexandre Dupuis, Yan Gao, Ning Guo, Elio Pone, Nicolas Godbout, Suzanne Lacroix, Charles Dubois and Maksim Skorobogatiy

*École Polytechnique de Montréal, Montréal H3C 3A7, Canada.
http://www Photonics.phys.polymtl.ca*

Abstract: Microstructured biodegradable optical fiber is fabricated featuring 1.1 dB/cm loss. Two cellulose butyrate tubes separated with hydroxypropyl cellulose powder were co-drawn into a porous double-core fiber offering integration of optical, microfluidic and potentially, drug release functionalities.

© 2006 Optical Society of America

OCIS codes: 060.2280 Fiber design and fabrication ; 170.3890 Medical optics instrumentation

1. Introduction

We present design and fabrication of a first, to our knowledge, biodegradable polymer optical fiber that simultaneously embodies optical, microfluidic, and drug release functionalities. Double-core porous fiber structure presents a small inner core suspended in air by the low refractive index particles separating it from the larger outer core (Fig. 1(a)). Double core structure enables laser power delivery as well as improved collection of the reflected light for passive sensing, cladding porosity enables microfluidics and active biological sensing, while biodegradable material combination offers a possibility of controllable drug delivery.

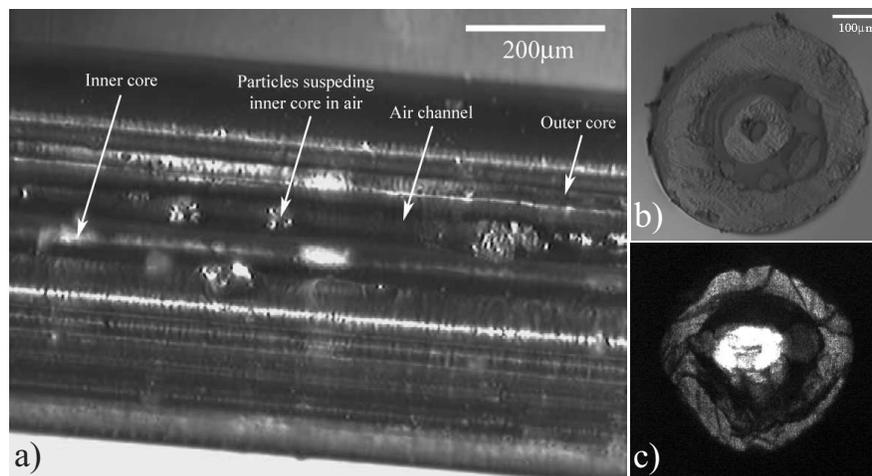


Fig. 1. a) Double core biodegradable microstructured fiber. The inner fiber is suspended in air by the powder particles. b) Fiber crosssection. c) Power distribution in the fiber crosssection after 3cm of propagation.

Due to their bio-friendly material composition and low cost of fabrication, microstructured polymer optical fibers have recently received much attention in a view of numerous bio-medical applications. Particularly, polymer microstructured optical fibers having porous structure offer a tremendous potential for simultaneous in-vivo medical sensing and laser power delivery, thus offering an integration platform for design of a complete diagnostic/laser treatment system in a single fiber. Moreover, if made of biodegradable materials such fibers can be impregnated with active pharmaceuticals such as anaesthetics or antibiotics enabling controllable release of chemical therapeutics during treatment. In a diagnostic mode, a sample to be analyzed can be pumped through the interstices of a porous fiber, while the light guiding through the fiber core can be used for detection. For example, Jensen and al. [1] have demonstrated fluorescence detection of selectively captured antibodies that were labelled with fluorescent markers. They also found that deposition of a sensing bio-layer is considerably easier if done on a polymer surface than on a glass surface, making polymer fibers better suited for bio-sensing than the glass ones. Recently, the use of dual-cladding optical fibers [2, 3] has attracted a lot of interest in the field of fluorescence microscopy as such structure permits single-mode delivery of the excitation pulse through a smaller core, and efficient multi-mode collection of the signal (fluorescent light) by

the larger core of higher numerical aperture [2, 3, 4, 5]. In a laser delivery mode, hollow core microstructured fibers have been demonstrated to deliver tens of watts of laser power almost anywhere in the visible and IR, enabling flexible delivery of power from the medically important $Nd:Yag$, $Er:Yag$ and CO_2 lasers [6].



Fig. 2. Photographs of the biodegradable, double clad, porous fiber preform, and its crosssection.

2. Fabrication and Characterization of the Fiber

Fiber preform (Fig. 2) was prepared using commercially available cellulose butyrate tubes of different diameters that have refractive index of 1.475. The smaller tube has inner and outer diameters of 1/8 and 1/4 inch, respectively, whereas the larger tube has inner and outer diameters of 3/8 and 5/8 inch, respectively. The smaller diameter tube, which forms the inner of the two fiber cores, was sealed at both ends with Teflon tape and placed in the middle of the larger tube that formed the outer core. In the final fiber structure the air hole of the inner tube could be collapsed or left open depending upon application. The space between the tubes was then filled with a polydisperse hydroxypropyl cellulose powder having refractive index of 1.337, in order to obtain a lower index inner cladding. The glass transition temperatures of cellulose butyrate and hydroxypropyl cellulose are estimated to be $95^{\circ}C$ and $120^{\circ}C$, respectively. As the powder has significantly higher melting temperature than the tubes, it remains in a powder state during the drawing process. The preform was preheated in the furnace of the drawing tower at a temperature of $150^{\circ}C$ for one hour and the fiber was subsequently drawn around $180^{\circ}C$.

The biodegradable fiber was drawn down to a diameter of $450\ \mu m$, and a standard cutback measurement was performed to give fiber transmission loss of 1.1 dB/cm at $\lambda = 630\ nm$. Distribution of power in the fiber crosssection Fig. 1(b) after 3cm of propagation is shown in Fig. 1(c), where nonuniformity in the power distribution is mostly due to the fiber end distortion caused by cutting. In Fig. 1(a) three light sources were used to visualize the particles in the cladding. Powder particles that remained intact during the drawing process are clearly seen to be supporting the inner core. It is difficult to estimate the air fraction of the inner cladding but the resulting structure is very porous. The effective index of refraction of the inner cladding is thus very close to that of air. It is worth mentioning that Kominsky et al. [7] have attempted a similar structure in silica. The marked difference is that they packed silica powder between two silica tubes and the resulting fiber had a random pattern of holes. Since the powder was of the same material as the tubes, those holes had randomly collapsed leaving longitudinal bubbles of random length within the inner cladding.

Finally, we report preliminary results on degradation of optical power transmitted through the fiber operated suspended in a deionized water. As the fiber is made of biodegradable materials, with the hydroxypropyl cellulose powder dissolvable in water, we expect that fiber optical properties should degrade when exposed to water. In a typical measurement of a transmitted power through a 2cm fiber piece suspended in water, transmitted power would reduce by a factor of two to five in the first 10 hours of exposure to water, remaining at an almost constant reduced value for the several following days. More experiments on microfluidic properties of such fibers are currently underway.

3. References

1. J.B. Jensen et al., "Selective detection of antibodies in microstructured polymer optical fibers", *Opt. Express* **13**, 5883 (2005).
2. M.T. Myaing et al., "Enhanced two-photon biosensing with double-clad PCFs", *Opt. Lett.* **28**, 1224 (2003).
3. L. Fu et al., "Nonlinear optical microscopy based on double-clad photonic crystal fibers", *Opt. Express* **13**, 5528 (2004).
4. J.Y. Ye et al., "Biosensing based on two-photon fluorescence through optical fibers", *Opt. Lett.* **27**, 1412 (2003).
5. S.P. Tai et al., "Two-photon fluorescence microscope with a hollow-core PCF", *Opt. Express* **12**, 6122 (2004).
6. G. Dellemann, et al., "Perfect mirrors extend hollow-core fiber applications," *Photonics Spectra* **37**, 60 (2003).
7. D. Kominsky et al., "Generation of random-hole optical fiber", *Opt. Lett.* **28**, 1409 (2003).