



HAL
open science

Silicon-core optical fiber with losses below 0.2dB/cm

M. Kudinova, G. Bouwmans, H. El Hamzaoui, R. Habert, S. Plus, B. Chazallon, R. Bernard, K. Baudelle, A. Cassez, O. Vanvincq, et al.

► **To cite this version:**

M. Kudinova, G. Bouwmans, H. El Hamzaoui, R. Habert, S. Plus, et al.. Silicon-core optical fiber with losses below 0.2dB/cm. OSA Advanced Photonics Congress (AP) 2020 Specialty Optical Fibers ((Optical Society of America, 2020), Jul 2020, Washington, United States. pp.SoM4H.2, 10.1364/SOF.2020.SoM4H.2 . hal-03416532

HAL Id: hal-03416532

<https://hal.science/hal-03416532>

Submitted on 5 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Silicon-core optical fiber with losses below 0.2dB/cm

M. Kudinova¹, G. Bouwmans¹, H. El Hamzaoui¹, R. Habert¹, S. Plus¹, B. Chazallon¹, R. Bernard¹, K. Baudelle¹, A. Cassez¹, O. Vanvincq¹, M. Marinova², N. Nuns², J. Troles³, L. Bigot¹

¹ Univ. Lille, CNRS, UMR 8523 - PhLAM - Physique des Lasers Atomes et Molécules, F-59000 Lille, France

² Univ. Lille, CNRS, INRA, Centrale Lille, ENSCL, Univ. Artois, FR 2638 – IMEC – Institut Michel- Eugène Chevreul, F-59000 Lille, France

³ CNRS, ISCR - UMR 6226, Univ. Rennes, F-35000 Rennes, France

laurent.bigot@univ-lille.fr

Abstract: Silicon-core fibers were drawn into hundreds of meter-long spans. The regular crystalline structure of the core and the absence of oxygen contamination are demonstrated together with loss below 0.2 dB/cm from 1250 to 1650 nm.

1. Introduction

Having linear and non-linear properties complementary to those offered by conventional silica optical fibers while continuing to use fibers as compatible as possible with them is a quest that the advent of hybrid fibers, such as the semiconductor core / silica cladding fibers, gradually made it realistic. As it is very widespread in integrated photonics, silicon is one of those materials that is highly desirable to adapt to the fiber geometry so as to facilitate, for example, the interfacing between planar and fiber waveguides. Moreover, due to its linear and nonlinear properties very different from the ones of silica glass, the availability of silicon-core fibers is opening many opportunities for nonlinear applications in the mid-IR domain. Since 2006, different approaches have been developed to fabricate silicon-core fibers and impressive results have been reported such as opto-electrical functions or, more recently, supercontinuum generation [1-4]. Molten core drawing (MCD) and high-pressure chemical vapor deposition (HPCVD) are two techniques that have been largely documented in the literature. Both necessitate to post-process the as-manufactured fibers to reach core dimensions and background losses compatible with an application in photonics. This post-processing generally consists in tapering or annealing the as-manufactured fibers so as to improve their core crystallinity and, in some cases, to reduce the fiber section to achieve a core diameter of 1-2 μm , compatible with the final application. Applying such protocols, it is possible to obtain centimeter-long pieces of fibers with losses below 1-2 dB/cm: a value of 0.47 dB/cm at 1550 nm still recently constituted today the state of the art [5]. Obtaining longer pieces of fiber (several tens of centimeters) with even better loss value would however benefit to many applications, especially nonlinear photonics for which the factor of merit is generally considered as a trade-off between nonlinearity and losses. It is the aim of this paper to present recent results obtained on low-loss silicon-core fibers elaborated by an alternative approach.

2. Main results

The silicon-core fibers that are considered in this work have been manufactured applying a variant of the stack-and-draw method, largely developed in the context of photonic crystal fibers manufacturing. A commercially-available polycrystalline silicon rod is inserted in the center of a stack made of pure silica capillaries. This stack is sleeved into a tube and then drawn into several meter-long canes of few millimeters in diameter. One of those canes, once sleeved into a second tube, is drawn into a fiber. Depending on the drawing parameters and the dimensions of the tubes, optical fibers with core diameter ranging from 0.8 to 3.5 μm can be obtained. A scanning electron microscope (SEM) image of a 3.3 μm core diameter fiber is illustrated on Fig. 1, left. One should note that the silicon material finally undergoes two high temperature processes before reaching its final state. However, due to the availability of a meter-long cane, stable drawing conditions can be achieved during the second step of the process and long spans of fibers can be obtained, typically longer than 100 m.

The structural properties of the core material have been investigated by Raman spectroscopy, high-resolution scanning transmission electron microscopy (HR-STEM) and time-of-flight secondary-ion mass spectroscopy (ToF-SIMS) on samples of fibers prepared using focused ion beam (FIB). A good compositional contrast between the core and the cladding materials is observed, without evidence of oxygen diffusion from the silica cladding into the core. The core material appears crystallized and regular when studied on both transverse and longitudinal cuts of fiber. These good structural properties result in interesting optical properties. Optical losses have been measured using a supercontinuum source injected into a high numerical aperture fiber butt-coupled to the silicon-core fiber, the output light being collected by a multimode fiber connected to an optical spectrum analyzer. As can be seen on Fig. 1, right, the

background losses are below 0.2 dB/cm from 1250 to 1650 nm. Such a value is similar to the best values reported for silicon-on insulator (SOI) waveguides.

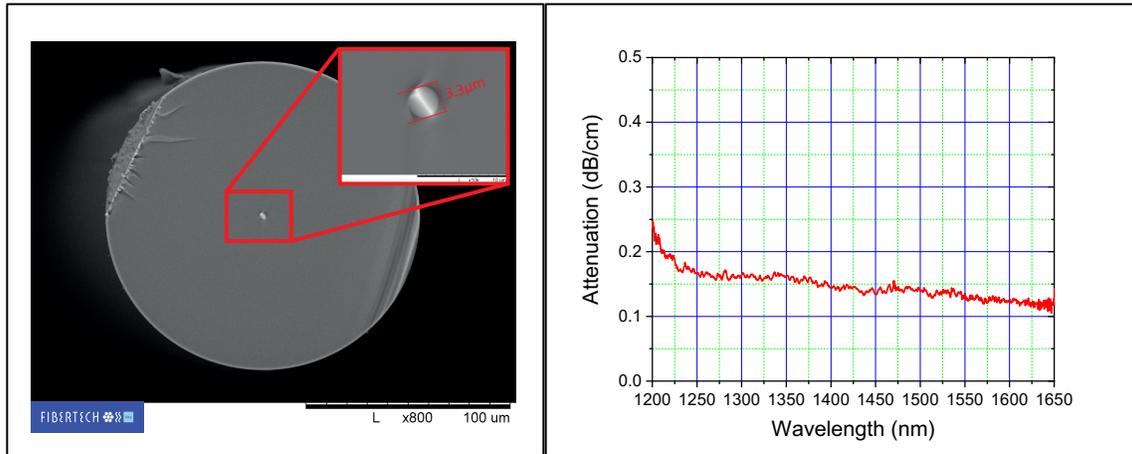


Fig. 1. Left: SEM image of a silicon-core fiber obtained from the rod-in-stack method used in this work. Right: spectral attenuation of the 3.3 μm core diameter fiber.

In conclusion, we report on a two-step method derived from the stack-and-draw technique and used to manufacture low-loss silicon-core fibers. The reported background losses are more than 2 times smaller than the state-of-the-art already reported for similar fibers, without the need to post-process the fibers. Such fibers are now available for applications in photonics such as nonlinear photonics in mid-IR region.

3. References

- [1] P.J.A. Sazio, A. Amezcua-Correa, C.E. Finlayson, J.R. Hayes, T.J. Scheidemantel, N.F. Baril, B.R. Jackson, D-J. Won, F. Zhang, E.R. Margine, V. Gopalan, V.H. Crespi and J.V. Badding, "Microstructured optical fibres as high-pressure microfluidic reactors", *Science* 311, 1583-1586, 2006
- [2] J. Ballato, T. Hawkins, P. Foy, R. Stolen, B. Kokuoz, M. Ellison, C. McMillen, J. Reppert, A. M. Rao, M. Daw, S. Sharma, R. Shori, O. Stafsudd, R. R. Rice, and D. R. Powers, "Silicon optical fibre", *Optics Express* 16 (23), 18675-18683, 2008
- [3] N. Healy, U. Gibson and A.C Peacock, "A review of materials engineering in silicon-based optical fibres", *Semiconductor Science and Technology*, 33(2) 023001, 2018
- [4] Ren, H., Shen, L., Runge, A. F. J., Hawkins, T. W., Ballato, J., Gibson, U., and Peacock, A. C., "Low-loss silicon core fibre platform for mid-infrared nonlinear photonics," *Light: Science and Applications* 8, 2019
- [5] X Ji, S. Lei, S-Y. Yu, H. Y. Cheng, W. Liu, N. Poilvert, Y. Xiong, I. Dabo, S. E. Mohny, J. V. Badding and V. Gopalan, "Single-Crystal Silicon Optical Fibre by Direct Laser Crystallization", *ACS Photonics*, 4(1) 85-92, 2017