LAWOFS 2024

LATIN AMERICAN WORKSHOP ON OPTICAL FIBER SENSORS

IBERO-AMERICAN EDITION

May 20-22, 2024
Campinas, Brazil

TECHNICAL PROGRAM AND BOOK OF ABSTRACTS

TECHNICAL CO-SPONSORSHIP

IEEE

IEEE Photonics Society

REALIZATION

sbmo Sociedade Brasileira de Micro-ondas e Optoeletrônica

UNICAMP

Impact of axial nonuniformity of cylindrical microresonators on the Q-factor of whispering-gallery modes.

J. Julián-Barriel[1,*], M. Delgado-Pinar[1,2], A. Díez[1,2], M. V. Andrés[1,2]

[1]Laboratory of Fiber Optics, ICMUV, Burjassot, Spain
[2]Departament de Física Aplicada y Electromagnetisme, Universitat de València, Burjassot, Spain
*juan.julian@uv.es

***Abstract*— An experimental investigation of the Q-factor of whispering-gallery modes (WGMs) of commercial optical fibers as cylindrical optical microresonators with slight axial non-uniformities is presented. The radius profile along a length of the fibers was measured with sub-nm resolution using WGMs. A large spectral broadening of WGM resonances was observed in fibers with radius fluctuation in the range on few tens of nm. It is shown that there is a correlation between the Q-factor of the WGMs and the slope of the fiber radius.**

Keywords—optical fibers, whispering-gallery modes, optical microresonator.

I. Introduction

Optical WGMs are resonances formed in circular structures where light can recirculate and interfere with itself. They can be excited in different dielectric microstructures such as spheres [1], rings, toroids [2] or cylinders. Such optical resonances are supported by the refractive index step between the dielectric material and air, and their fields are tightly confined near the surface of the microresonator. The quality factor (Q) of these resonances, defined as the ratio between stored energy and dissipated energy in a cycle, can reach ultra-high values, up to 10^8. This feature allows using them in many applications [2], particularly for sensing [3]. The development of sensing applications based on WGMs rely in part on the Q-factor of the optical resonance; the narrower the resonance, the lower is the detection limit.

Commercial optical fibers are commonly used as cylindrical optical microresonators due to their availability, ease of use, and good surface quality. Additionally, commercial optical fibers exhibit an excellent axial uniformity, with typical radius variations in the nm scale along fiber lengths of tens of cm [4]. Such an axial non-uniformity, although very small, has a significant impact on the WGMs due to their high Q-factor. In the present work, we investigated experimentally on the spectral broadening of WGMs resonances in commercial optical fibers caused by the lack of fiber uniformity, and we obtained a good correlation between the fiber radius slope and the bandwidth of the optical resonances.

II. WGM's fundamentals

Resonant wavelengths and optical fields of WGMs can be calculated by solving Maxwell's equations in an infinite dielectric cylinder for waves propagating in the azimuthal direction [5]. WGMs in a microcylinder are separated into two families according to their polarization, i.e., transversal electric (TE^z) WGMs, and transversal magnetic (TM^z) WGMs. Selective excitation of WGMs of one of another family can be achieved by control of the polarization of the excitation optical signal. The resonant wavelength, λ_m, of each WGM can be expressed in terms of an effective refractive index n_{eff}, and depends on the mode order m, and the radius a, as follows,

$$\lambda_m = \frac{2\pi}{m} n_{eff} \cdot a \tag{1}$$

For a given WGM, a small change in the fiber radius Δa leads to a shift of the resonant wavelength $\Delta\lambda_m$ that can be approximated by,

$$\frac{\Delta\lambda_m}{\lambda_m} \approx \frac{\Delta a}{a} \tag{2}$$

III. Experimental procedures

Fig. 1 shows a scheme of the experimental setup. We employ a narrowband tunable laser (TL) centered at 1530 nm as light source. A fiber polarization controller (PC) is included to select the polarization of the excitation signal. The excitation of WGMs was achieved by evanescent field coupling [5] using a 3 μm waist fiber taper, fabricated at our facilities. In all experimental measurements, the fiber taper was positioned in contact with the fiber under test (FUT). A photodetector (PD) and an oscilloscope (OSC) is employed to register the transmittance spectrum of the system. An optical wavelength meter (WM) with 1 pm accuracy was used for the measurement of the WGMs' resonance wavelength.

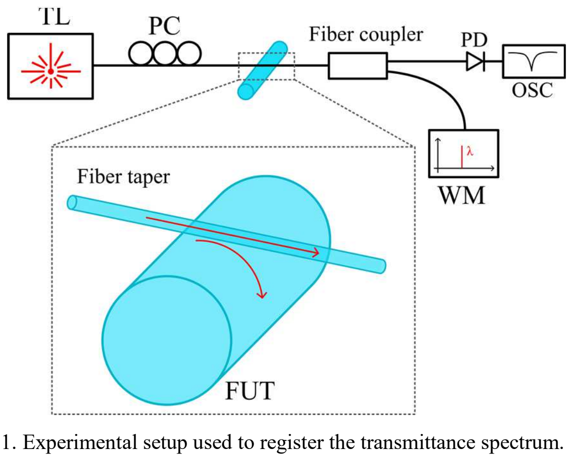

Fig. 1. Experimental setup used to register the transmittance spectrum.

We investigated two commercial optical fibers, a photosensitive fiber PS1250/1500 from FiberCore Ltd., and a standard telecommunication SMF-28e fiber from Corning Inc. For each fiber, a given WGM was selected, and its optical spectrum recorded at different axial positions along the FUT. Measurements were repeated several times to ensure consistency of the results.

©2024 SBMO - ISBN 978-65-89532-02-6

Authorized licensed use limited to: Miguel Andres. Downloaded on September 04,2024 at 20:19:19 UTC from IEEE Xplore. Restrictions apply.

IV. RESULTS

Experimental measurements of the WGM resonance wavelength along a section of FUT are shown in Fig. 3 and Fig. 4, for PS1250/1500 and SMF-28e fibers, respectively. Using Eq. (2), the radius fluctuation along the fibers was calculated, and it is depicted by the right axis. Fiber PS1250/1500 shows a variation of 120 nm along 11 cm fiber length, while SMF-28e fiber shows a much more uniform profile, with a radius variation of only 2.2 nm in 10 cm of fiber, which represents a $3{,}2 \cdot 10^{-3}$ %.

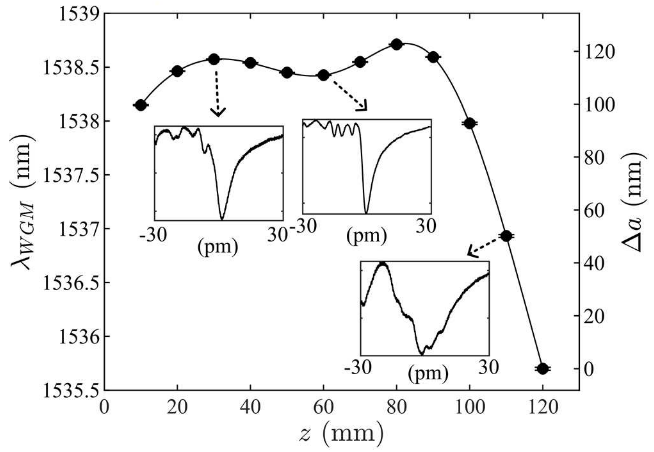

Fig.3. Measured axial profile of PS 1250/1500 fiber. Left axis: experimental WGM resonance wavelength. Right axis: radius change estimated from Eq. (2).

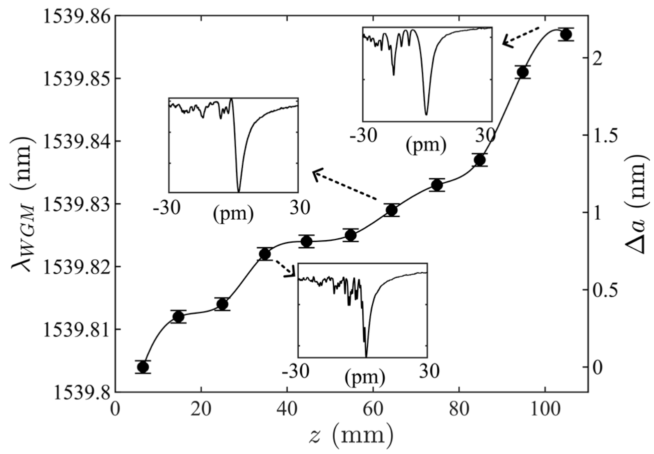

Fig.4. Measured axial profile of SMF-28e fiber. Left axis: experimental WGM resonance wavelength. Right axis: radius change estimated from Eq. (2).

The WGM transmittance spectrum recorded at three positions along the fibers are included in Figs. 3 and 4. In the case of SMF-28e fiber, no marked differences can be noticed in the shape of the transmission notches. However, spectra recorded in the case of PS1250/1500 fiber are remarkably different. Thus, we investigated the bandwidth of the notch along the fiber and we contrasted it against the fluctuation of the fiber radius. Figure 5(a) shows the fiber radius slope ($\Delta a/\Delta z$) along the fiber section, while Fig. 5 (b) shows the measured full-width at half maximum (FWHM) of the notches. A correlation between FWHM and radius slope can be observed. The lowest FWHM values were obtained at fiber locations with radius slope close to zero. The increase in FWHM closely agrees with the increase in fiber radius slope.

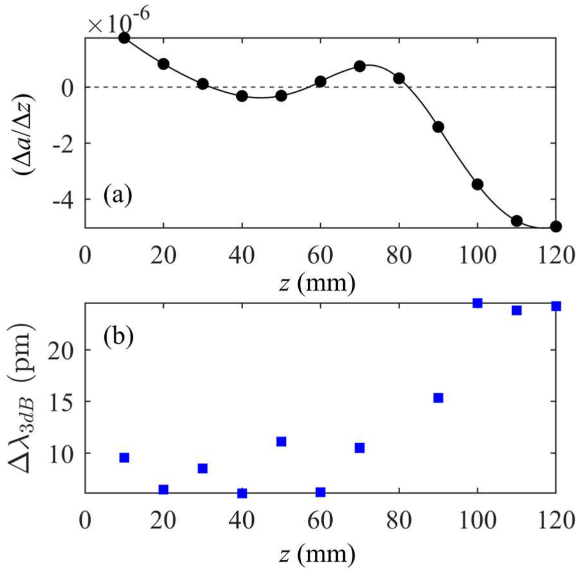

Fig.5. (a) Slope of the axial profile of the PS 1250/1500 fiber. (b) Full width at half maximum of the WGM measured in PS 1250/1500 fiber.

V. CONCLUSIONS

The bandwidth of WGM resonances of two commercial optical fibers, and its dependence on the fiber radius uniformity has been investigated. The fluctuation of fiber radius of SMF-28e fiber was within the nm scale, and changes of FWHM along the fiber were within our experimental uncertainty. The PS1250/1500 fiber shows a larger radius inhomogeneity, and resonances become clearly wider resonance. Our results show a clear correlation between radius slope and spectral width of the WGM. This effect can be explained by considering that, in zones with large radius slope, the resonator behaves as a cone with a small angle rather than a cylinder, which impacts on the shape and width of WGMs [6].

ACKNOWLEDGMENTS

This research was funded by the Ministerio de Ciencia e Innovación and co-funded by the European Regional Development Fund (Fondo Europeo de Desarrollo Regional, FEDER), grant number TED2021-130200B-I00 and the European Commission, grant number H2020-MSCARISE2019-872049. J. Julián-Barriel thanks the Conselleria de Educación, Universidades y Empleo for his ACIF grant.

REFERENCES

[1] A. Chiasera, Y. Dumeige, P. Féron, M. Ferrari and Y. Jestin, “Sperichal whispering-gallery-mode microresonators”, Laser & Photon. Rev. 4, 2010, pp. 457-482.

[2] K. J. Vahala, “Optical microcavities”, Nature, 424, 2003, pp. 839-846.

[3] J. Liao and L. Yang, “Optical whispering-gallery mode barcodes for high-precision and wide-range temperature measurements”, Light Sci. Appl., 10, 2021, 32.

[4] E. Alcusa-Sáez, A. Diez, M. Gonzalez-Herraez and M. V. Andres, “Improved time-resolved acousto-optic technique for optical fiber analysis of axial non-uniformities by using edge interrogation”, Opt. Express, 23, 2015, pp. 7345-7350.

[5] X. Roselló-Mechó, “Whispering gallery modes: advanced photonic applications”, Doctoral thesis, May 2019.

[6] M. Sumetsky, “Localization of light on a cone: theoretical evidence and experimental demonstration for an optical fiber”, Opt. Lett., 36, 2011, pp.145-1

Authorized licensed use limited to: Miguel Andres. Downloaded on September 04,2024 at 20:19:19 UTC from IEEE Xplore. Restrictions apply.