Measurement of the UV-induced radius decrease in a silica fiber by means of optic and acoustic resonances.

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ABSTRACT:

In this work, we present experimental measurements of the magnitude of the compactation of a photosensitive, commercial fiber (PS1250 from Corning), when it is UV-irradiated at the fluencies usually employed for UV-inscription of fiber gratings. Such compactation of silica has been identified as the source of scattering loss in gratings. However, there are scarce data about its magnitude in fibers.

In order to measure the UV-induced decrease of fiber radius, sensing techniques must present high sensitivities and low detection limits. Here we present two methods with these characteristics: the use of optical azimuthal resonances, so called Whispering Gallery Modes Resonances (WGMRs), and optically generated transversal radial acoustic resonances, combined with WGMRs

In this abstract we present the experimental procedures and the data provided by each technique. The further analysis of the results to analyze the effect of UV radiation on different parameters of the fibre is work in progress.

Key words: optical fibre, optical resonator, acoustic resonator, Whispering Gallery Modes, optomechanics.

1.- Introduction

UV-radiation is a basic tool for one of the most popular techniques to fabricate gratings, which nowadays forms part of almost every optical fibre system. This radiation is used to change the refractive index of a photosensitive fibre (usually, with a boron codoped core) in a permanent way. Together with this change in the refractive index, there are other side effects: the increment of absorption loss and the compactation of the silica material, which also results in an increment of the loss due to scattering [1]. A visual evidence of this compactation of the silica was reported in [2], where an AFM image shows the modulation in the surface of a preform of an optical fiber when it was UV-radiated.

There is scarce data about the magnitude of such compactation of the silica material in optical fibers. Its origin relies on the high density of energy which is used to illuminate fibres while the inscription of gratings, which, combined with the absorption of the core of the fibre at UV wavelength, increases its temperature and, as a result, densifies the material. Both the pure silica of the cladding and the doped silica of the core suffer from compactation of the material when they are UV-illuminated, but the effects on the core can be one order of magnitude bigger. Thus, the main effect will be a compactation of the core that induces a radial stress at the whole cladding, resulting in a change of the radius of the fiber and the refractive index of the core and cladding silica due to the strain-optic effect.

In order to measure some parameters of fiber materials, techniques with high sensitivity and low detection limit need to be used. In [1], Whispering Gallery Modes Resonances (WGMRs) were used to measure the above-mentioned increment of loss in different commercial photosensitive fibers induced by UV radiation. Also, optically-generated, transversal acoustic resonances (TRARs) in an optical fiber have been demonstrated useful to measure with high accuracy the Poisson coefficient of silica in a fiber [3]. Both methods rely on the high Q factor of the resonances (up to 10^7 for WGMRs and 10^3 for acoustic radial resonances), that is, their narrow bandwidth, and their sensitivity to the variation of the radius and the refractive index of the resonator (the optical fibre in both techniques).

In this work we use both techniques separately: first, azimuthal optic WGMRs alone, and second, radial acoustic resonances combined with WGMRs, to measure the densification of a photosensitive silica fibre when it was exposed the usual dose of UV radiation employed to inscribe a fiber Bragg grating on it.

2.- Whispering Gallery Modes Resonances technique

WGMRs are optical, azimuthal resonances propagating in spherical or cylindrical microresonators (MRs). In our case, a section of bare, optical fiber will play the role of the cylindrical MR. Their resonant wavelengths, λ_R, are given, considering a perfectly isotropic material, by

$$\lambda_R = \frac{2\pi}{m} n_{eff} a \qquad (1)$$

where m is the azimuthal order, n_{eff} the effective refractive index of the resonance, and a is the radius of the fiber. If one of these last parameters change because any procedure performed on the fibre (in our case, the UV-irradiation), the resonance will shift in wavelength. Fig. 1 (up) depicts the operation principle of this method.

As mentioned, the UV-irradiation will produce a collapse of the fiber and, as a consequence, it will introduce a transversal strain in the fiber. Both effects will shift the wavelength, but with a different sign: λ_R will shift towards *blue* wavelengths as the radius diminishes because a geometrical effect. Moreover, the strain-optic effect will introduce an additional wavelength shift, depending on the sign of the strain (a compression, in our case, that is, towards *red* wavelengths). In our calculations, we will assume that the shift is only due to an *effective* decrease of the radius, since the overall effect is a shift towards *blue* wavelengths. Due to this assumption, the calculated value for the variation in the radius of the fiber will be an underestimation.

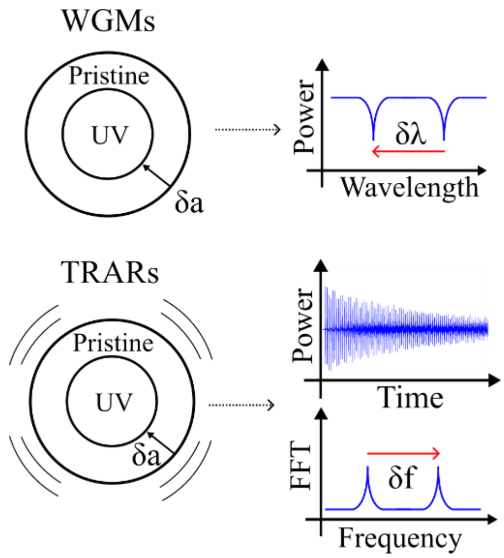

Fig. 1: Principle of operation of the (up) WGMRs technique, (low) TRARs technique.

Fig. (2) shows the setup employed for the measurements. The TL is a tunable light laser emitting in the C-band, with a linewidth lower than 30 kHz. The fine wavelength tuning scans over ~90 pm and the central wavelength of the scans was measured using a Burleigh WA-1600 wavelength meter (resolution: 0.1 pm). A PC is introduced to excite separately the family of TE and TM WGMRs. A microfiber, MF, fabricated by tapering a conventional telecom fiber (taper waist: 3 µm, length: 5 mm) is used to couple the light into the MR; both are placed perpendicularly. Finally, a photodetector PD and an oscilloscope (bandwidth: 350 MHz) are used to register the optical output of the taper. The WGMRs appear as a series of attenuation notches. Once selected the TE or TM family of the resonances, the measured wavelength shift due to UV-irradiation will be independent of the azimuthal order chosen to perform the experiment (the difference in the results between two consecutive azimuthal orders is lower than 0.1% [4]). Fig. 2 shows a scheme of the setup.

This technique provides axial resolution, since the optical field of the WGMR extends axially over few hundreds of μm (the exact figure depends on the Q value of the MR). Then, by placing the contact point between the taper and the MR at several positions, it is possible to measure at different points along the MR with a good accuracy. We will measure at different points of the MR to ensure repeatability.

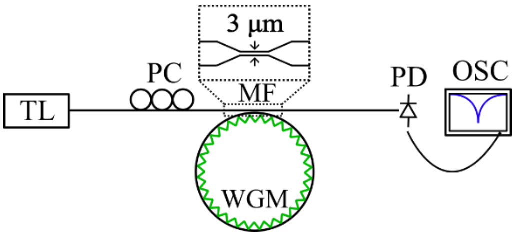

Fig. 2: Scheme of the setup for the WGMRs technique.

Our MR consists on a section of bare boron codoped photosensitive fiber (PS1250 from Fibercore). A length of 10 mm was UV-irradiated with a DC fluence of 150 J/mm^2, at the wavelength of 244 nm. The WGMRs were measured at three different points of the pristine, and three of the UV-irradiated sections, for TM polarization. The selection of this family is due to the fact that these WGMRs are sensitive only to the variation in radius, since there is not variation in the axial component of the refractive index [4].

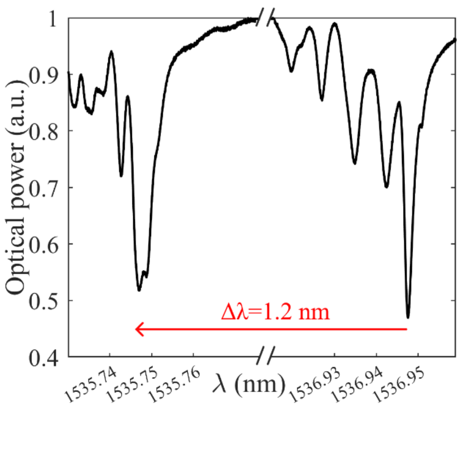

Fig. 3: Wavelength shift of a TM-WGMR when it is measured in the pristine (right) and the UV-irradiated (left) section of the MR.

Fig. 3 shows a typical trace of the experimental results. The linewidth of the selected resonance is 2.7 pm (Q=5.4×10^5). The wavelength shift for the TM family, averaged for the set of three different positions at each section, was of $\Delta\lambda_R$ = 1.19±0.07 nm. Since this value is higher than the fine tuning range of the TL, we ensured that the wavelength was accurately determined for each measurement using the Burleigh wavelength meter. According to this wavelength shift, we can calculate an effective variation in the radius

$$\Delta a_{WGMR} = -49 \pm 2 \text{ nm}$$

3.- Transversal Radial Acoustic Resonances Technique

In this method, the optical fiber plays the role of the optical MR, since it supports the WGMRs employed to interrogate the radius variation, but also of an acoustic MR, as we will excite mechanical resonances on it. To do so, we will launch high power, optical pulses (1064 nm, 700 ps width, 6 kW peak power in the MR) through the core of the MR. Due to electrostriction, such pulses will generate mechanical waves; in this case, transversal radial, and transversal torsional-radial resonances will be generated. The principle of operation is depicted in Fig. 1 (lower scheme). The setup employed is shown in Fig. 4. In this case, a high frequency photodetector and oscilloscope (bandwidth: 3 GHz) are employed to register the optical traces.

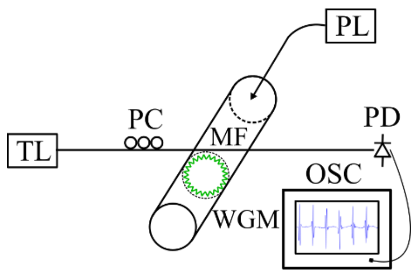

Fig. 4: Scheme of the setup for the TRARs technique. PL: high peak power pump laser.

In order to measure the acoustic resonances, WGMRs will be employed, as in the previous section. The radius of the fiber will change accordingly to the frequency of the series of TRARs generated. It is worth to note that, due to the field structure of the torsional-radial resonances, which do not show a net change in the radius, the WGMRs will not be able to detect them. Thus, by means of this technique, only the TRARs will be measured.

Fig. 5 shows an example of the registered optical trace and its Fourier Transform (FT), when the TRARs are detected by a TM-WGMR as the one depicted in the previous section, see Fig. 3. Again, the measurements were performed at three different points of the pristine, and other three of the UV-irradiated MR.

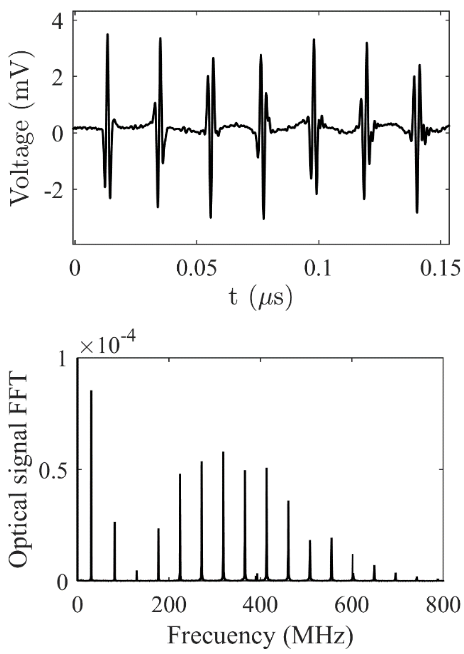

Fig. 5: Output signal (up) and its FT (low) of the trace registered in the experiments.

The frequencies of the different radial orders of the TRARs (each one being a peak in the FT of Fig. 5) shift in wavelength when comparing the measurements at the pristine and the UV-irradiated MR, each one according to their own dispersion curve of the frequency vs. radius. From the analysis of the shift of all of them as a whole, one can extract information about the change in the radius due to the UV-radiation. Fig. 6 shows a detail of the frequency shift of one particular TRAR, the ninth peak observed in the FT in Fig. 5 ($TRAR_{0,9}$).

From the analysis of the frequency shift of the whole set of TRARs resonances, it is possible to extract a first estimate of the variation of the radius obtained by means of this technique,

$$\Delta a_{TRAR} = -185 \pm 6\,\text{nm}$$

This value is three times the one obtained when using the WGMRs. We are aware that, when irradiating the fibers, we might change the acoustic properties of the materials, thus both values might not be directly comparable. The detailed evaluation of the effect of the UV radiation on the radius and the acoustic properties is work in progress at the moment.

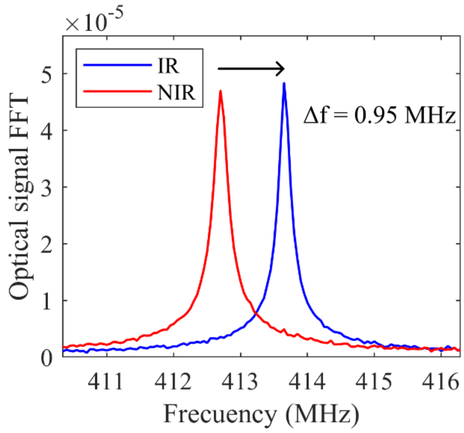

Fig. 6: Frequency shift of the $TRAR_{09}$. Left: pristine fiber. Right: UV-irradiated fiber.

4.- Conclusions

In this paper we have shown two different techniques with a detection limit low enough to directly measuring the change in the radius of a photosensitive fiber when it is UV-irradiated. This UV-light causes a compactation of the fiber material, primarily the one of the nucleus and, as a consequence, a transversal strain is induced in the fiber. This leads to a decrease of the radius and a variation of the transversal refractive index.

In a first place, WGMRs are used alone to measure the decrease in the radius. This tool provides axial resolution, thus we can interrogate several points of the MR and determine the difference between the UV-irradiated and the pristine fibers. TM resonances are employed since they are not sensible to the variation induced in the transversal component of the refractive index, thus the resonant wavelength of the WGM will shift only due to the decrease of radius. By using this technique, we obtain that the fiber radius decreased in 49±2 nm.

In a second place, we combine optical (WGMRs) and acoustic (TRARs) resonances to perform the same measurements. We optically generate the TRARs in the MR using a pulsed, high peak power, pump laser at 1064 nm via electrostriction. The TM-WGMR will detect the effective modulation in the radius due to the mechanical resonance. Again, the use of WGMRs as the interrogation tool allows measuring at different points of the resonator, in and out of the UV-irradiated section. The acoustic frequencies of the TRARs excited in the MR are different if the measuring point is in the pristine or in the irradiated section. From the shift between them, we made a first estimation of the variation in the radius due to the UV-induced compactation, resulting to be 185±6 nm.

In order to have a true comparison between the values obtained from both techniques, the currently work is centered in a detailed evaluation of the different changes induced in the fiber material by the UV-radiation, which might affect its acoustic properties.

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