DESIGN FOR SENSOR BASED ON SUSPENDED CORE MICROSTRUCTURED OPTICAL FIBER

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Abstract: In the paper is proposed the design for a sensor based on a new three-hole microstructured optical fiber. The simulations show that the size of the core has a great effect on its applicability on both sensing and transmission. The core of the fiber should have the diameter around 1μm to 6 μm and the experimental results prove that the fabricated optical fiber would make a good sensor with losses measured around 4,5 dB/m.

Keywords: *fiber sensor, microstructured optical fiber (MOF), cutback technique for attenuation measurements.*

I. INTRODUCTION

Suspended-core fibers (SCF) are the types of fibers in which holes run along it so that the core is suspended by very thin layers that separate the holes.

The SCF design was first proposed in 2001 by Monro et al. [1], more exactly, the presented design had a core with small dimensions so that the fiber was single-mode. The core size was so small that 17% of the mode energy was in the air when the wavelength was 1550 nm. In the year 2007 Webb et al. [2] presented a technique which would surpass the stacking method. This technique was based on creating holes through mechanical drilling in the preform stage. The next step is to manipulate the shape of the holes in the drawing stage so that the resulted fiber would have the core suspended and supported by some very small struts (3 in this case).

This technique opened possibilities for new SCF geometries, for example the Raman spectroscopy and fluorescence applications, and other.

In the present time, the main applications in which this fiber types are used is optical sensing [3] and nonlinear optical effects, in other words supercontinuum sources [4, 5] and fiber lasers [6].

Suspended core fibers (SCFs) are widely known for their applications such as gas sensing cells [7], exposed MOFs used for real-time fluorescent sensing [8], Surface-plasmon-resonance sensor [9] and other.

Microstructured optical fibers (MOF) are optical fiber waveguides where manipulating the waveguide structure has more importance in guiding than its index of refraction.

MOFs are well-known for their use in sensing applications. They have longitudinal air holes that are used to confine the light with the assistance of their refractive index, also they could be used as tiny sample chambers. To take in consideration, the guided portion of the light that is located in these holes is usually used in many optical fiber sensing applications [10].

The stack and draw technique [11] is the most common one used to produce fibers. This technique relies on manual assembly of capillaries into an appropriate preform stack, whose structure corresponds to the desired fiber structure. The size of the air-holes and their regularity can be controlled by tuning process parameters such as temperature, mechanical tension, drawing speed.

In sensing applications, it’s important that a part of the guided field is exposed to the external environment. If the amount of exposed guided field is increased then there is a greater shift in Bragg wavelength relative to the sensitivity, in other words, the external refractive index [12].

The D-fiber should also be taken in consideration, being a variation of the well-known step-index fibers. This type of fiber is used for propagation in external fields, having as a downside the sensitivity limitations regarding the external refractive index [13, 14]. The main reason for these limitations is that the refractive index of the opened side of the D-fiber differs from the core or cladding boundary, in other words, the propagation does not remain on the sensing part. As a result, the D-fibers have an external field percentage the order of only 0.1-0.2% [15].

We propose in this paper to produce a MOF with the core having an effective diameter between 1-6 μm, simulate the equivalent model and characterize the obtained fiber. This fiber will be used in sensor applications based on the obtained results.

II. SENSOR DESIGN

II.1 Simulations

In the simulation stage, we realized a simulated version of the final version of the optical fiber using COMSOL Multiphysics 5.0 (Figure 1).

The refractive index value of the core (3μm) is approximately n=1.451 for the wavelength λ=1.55 μm. For this fiber (Figure 2), the core has a lower refractive index

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than the Silica Glass (n=1.4). An important factor would be that the three holes were considered as being filled with air (n=1).

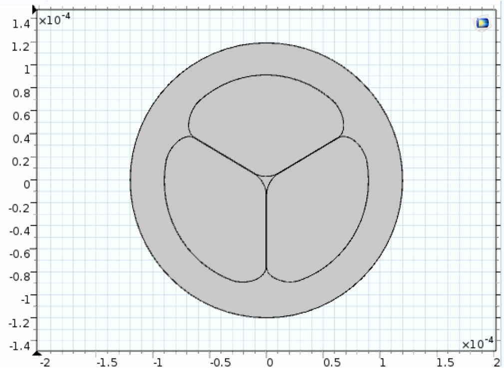

Figure 1. COMSOL version of the optical fiber

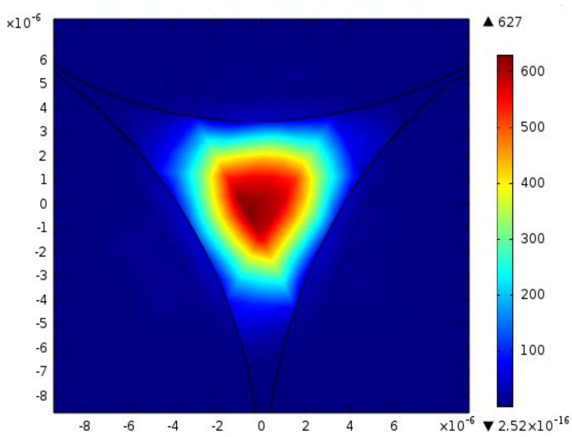

Figure 2. COMSOL version of the optical fiber – Electrical Field (Effective Mode Index=1.4)

In the simulation stage, it's important to notice the events that occur regarding the electrical field inside a core with an effective diameter of 3 µm.

The purpose of these simulations is to verify if the fiber obtained in the drawing stage is suited for sensor applications.

The energy outside the core for this fiber (core with the diameter of 3), marked with red lines (Figure 3), has importance of 1-3.5% in comparison to the maximum value. In other words, the fiber would make a decent light conductor, but, most importantly, a good sensor.

The amount of energy outside the core is very important in sensing applications, because it's easier to measure parameters, for example: temperature, pressure strain and other. The main disadvantage is that the fiber requires a great amount of energy to have a better understanding regarding its sensing capabilities.

In the Figure 4 is presented the design of the final preform.

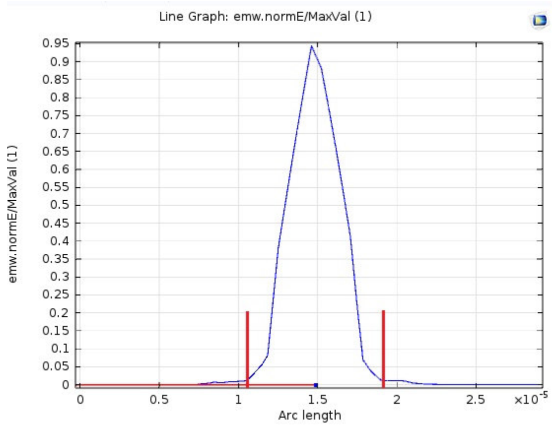

Figure 3. Simulation results for a core diameter of 6 µm

Figure 4. Design of the final preform

II.2 Preform stage

The main goal of the preform stage was to create a sensor based on an optical fiber that has a core with an effective diameter of approximately 1-6 µm. In order to reach this kind of value, we used: a) GE214 with 6 mm inner diameter (ID), 12 mm outer diameter (OD) and a thickness of 3 mm; b) F300 with 20 mm ID, 25 mm OD with a thickness of 2.5 mm.

The capillary's thickness is a direct influential factor to the fiber's core diameter. Using the drawing tower, the F300 had its dimensions reduced approximately 10 times (2.2 ID and 2.6 OD) so that it would fit in the main tube (GE214). The main reason for using this tube as capillaries is that its thickness would contribute to realizing a final core of the desired dimensions (1-6 µm). The ratio of ID/OD is important because it influences the core size, for instance a ratio of 0.66 (ex. ID 2 mm and OD 3 mm) is relatively far from the unitary value which will result in a core with a diameter of at least 10 µm, and a ratio of 0.8 (ex. ID 2.5 mm and OD 3 mm) will result in a core with a diameter of 7 µm in the most unfavorable case.

II.3 Drawing stage

Using the stack and draw technique and the drawing tower, we managed to make the final desired fiber. Some parameters that are worth mentioning: V=21.6 m/s; T=2060°C; L=78g, where V is the drawing speed, T is the drawing temperature and L is the mechanical tension (Figure 5).

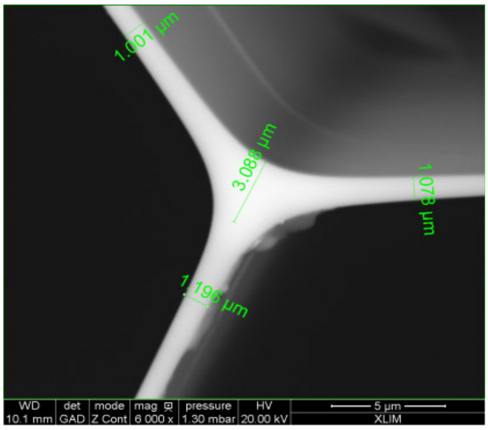

Figure 5. The resulted fiber after the drawing stage

Using a microscope, we obtained the approximated dimensions of the fiber's core and the wires that suspend it.

The hole and wire dimensions are not considered to be important now, but not the same could be said about the core. The core's diameter, as shown in the Figure 4, is approximately 3 µm, so it's in the desired domain.

III. EXPERIMENTAL RESULTS

In order to characterize the fiber, we used the cutback technique and the devices: laser source and Spectrum analyzer. One of the advantages of using this technique is that it allows measurement of the fiber characteristics without introducing errors due to variation in the launch conditions. For example, the source remains the same before and after the cutback measurements [16]. The attenuation losses were obtained using a long sample of the fiber ($L1=5m$) with the power $P1$ and the shortened version ($L2=1m$) with the power $P2$ (1).

$$\frac{P_2 - P_1}{L_2 - L_1} = \frac{G}{L_{21}} \qquad (1)$$

Where G represents (2) and $L_{21}=4m$,

$$G[dB] = P_2\,[dBm] - P_1\,[dBm] \qquad (2)$$

As a result, the final form of the linear attenuation losses is (3) which is measured in dB per meter:

$$A = \frac{G}{L_{21}} \qquad (3)$$

The setup used for the measurements is depicted in Figure 6.

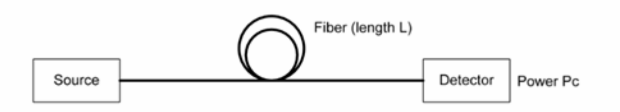

Figure 6. The cutback technique used for attenuation measurements

Using the cutback technique, we obtained the following graph (Figure 7).

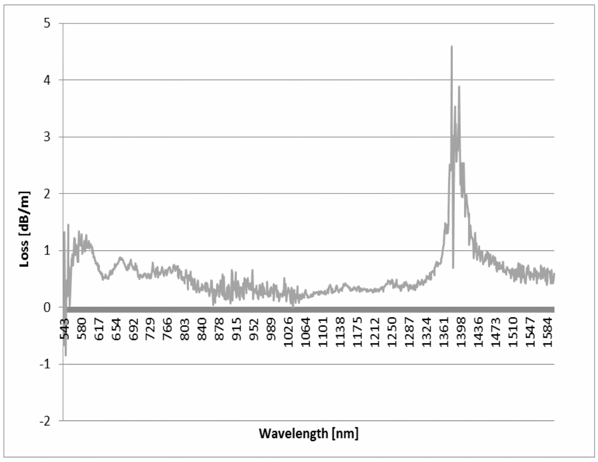

Figure 7. Linear attenuation using the cutback technique

From Figure 6 we can say that the fiber works best at the wavelengths [850-1200] nm because the attenuation losses are at the lowest values in the specified domain, more exactly the losses measured are around 0.33 dB. The most significant losses are registered in the [1300-1450] nm domain and have values the reach over 4.5 dB.

We connected one of the terminal parts of the fiber to the laser source and the other to a thermal camera to demonstrate the triangular shape of the core, so that we could obtain images of the fiber's core using different lenses (Figure 8).

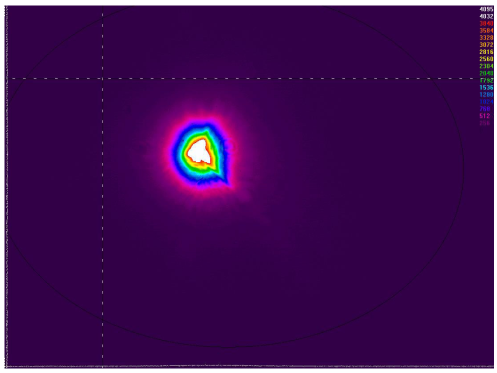

Figure 8. Fiber core using the thermal camera

The main reason of this experiment is to verify if the light that passes through the core of the fiber has a triangular shape, just like in the simulated version of the fiber.

We follow a procedure to expose the core of the fiber for different analytes measurements to obtain a fiber optic sensor. An adhesive substance was used to keep the fiber in a fixed position, this way it would be easier to use a polishing device to open a single hole of the fiber.

The first step is to fix a string of the fiber inside a small empty cylinder with a radius big enough to not cause possible damage to the fiber. Afterwards, an adhesive solution is to be used to fill the cylinder. The last step is to safely remove the fiber that is fixed to the solid solution from the cylinder without damaging it because the fiber is positioned at the surface of the solid form. The first polished fiber is considered as being a test-fiber and will give us information regarding the time needed to remove the resin solution, time to reach the cladding level and then expose the core of the fiber.

In Figure 9 the fixed optical is described after the main phase of the polishing process. After polishing, the light power losses are characterized in order to be ready for sensing applications, where the active area of the sensor is exposed to different analytes (Figure 10).

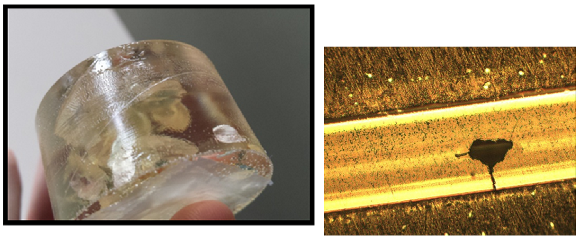

Figure 9. Optical fiber fixed to adhesive solid solution and Zoom-in of the hole of the fiber after polishing process

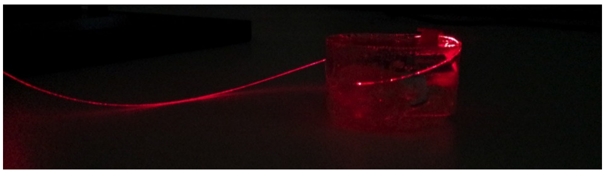

Figure 10. Light losses of the polished fiber, prepared for sensing applications

The main advantage of this method of exposing the fiber core is that it's simplistic and requires few technological resources. The main disadvantage is that it requires constant monitoring of the polishing progress.

IV. CONCLUSIONS

Using the stack and draw technique, we managed to create a 3-hole fiber structure for the drawing stage.

We managed to create with the drawing tower, 8 optical fibers from which 3 of them (4, 6, 8) are version of the final versions of the desired fibers with core diameters around 3-4 µm.

As observed in the simulation stage, fibers that make good conductors have a core diameter around 4-6 µm and fibers that make good sensors have a core diameter around 1-4 µm. As a result, the fibers obtained in the drawing stage are in the sensor domain.

We characterized the fiber using the cutback technique and obtained the linear attenuation graph.

The most important graph, the attenuation losses graph (Figure 5) suggests that the fiber should work as a sensor with the wavelengths that have losses 4.5 dB/m or higher, but at the same time, close enough to the 1400 nm wavelength. This value is relatively high in general cases because optical fibers are mostly used in long distance applications, but in the case of sensor applications, this is an acceptable value.

ACKNOWLEDGEMENTS

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