Microstuctured optical fiber losses in case of one-sided lateral contraction

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Abstract— **Deformation and stress distributions in microstructured optical fibers of two types in case of lateral contraction (compression) was calculated by the finite element method. The microstructured fiber and classical optical fiber sensitivity to lateral compression was experimentally investigated for the purpose of optical fiber sensor constructing.**

Keywords-component; optical-fiber sensor; microstructured optical fiber; lateral compression; finite element model

I. INTRODUCTION

Fiber-optical sensors for measurements of various physical values are widely used in science and engineering [1]. One of the fiber types is the microstructured optical fibers (MSOF) having cylindrical holes in the core. This light guiding core structure gives to the microstructured fibers new properties.

For various type of sensors the microstructures optical fibers are more attractive because they have significantly lower temperature dependencies in comparison with classical optical fibers [2] .

The influence of the lateral compression on optical losses in the classical fibers has been already systematically investigated [3]. As for the microstructured optical fibers, the investigations of this kind are not presented in the scientific papers in full.

In our paper we present results of experimental investigation on the effect of the lateral compression in optical fibers at the loading value from 0 to 45N in case of excitation of the optical fiber with monochromatic light. In our experiments the classical single mode microstructured fibers with several layers of airy holes were used. Also we used a classical optical fiber Corning SMF-28 as a comparison sample.

II. SAMPLES, MEASUREMENT TECHNIQUES AND RESULTS

The investigated optical fiber of the first type is a single material single-mode microstructured one with the following structure. The silica core with diameter of 14μm is surrounded by silica cladding with four full air hole rings inside the cladding arranged in a hexagonal structure (average diameter of the holes is 1.3μm, and the average hole spacing is 9μm). Diameter of the silica cladding is 125μm and diameter of the protective plastic coating is 245μm. A picture of the cross-section of this fiber is presented in Fig. 1.

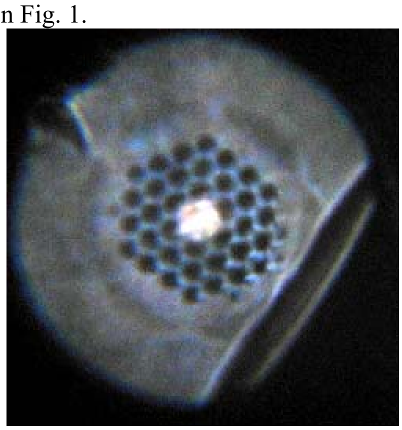

Figure 1 Cross-section of the investigated microstructured optical fiber of the first type

The second type optical fiber is a single material single-mode microstructured one with the following structure. The silica core with diameter of 10,2μm is surrounded by silica cladding with four full air hole rings inside the cladding arranged in a hexagonal structure (average diameter of the holes is 2.8μm, and the average hole spacing is 5.6μm). Diameter of the silica cladding is 125μm and diameter of the protective plastic coating is 245μm. Diameter of the fundamental LP_{01} mode in the fiber is ~ 8.9μm at λ = 632.8nm. A picture of the cross-section of this fiber is presented in Fig. 2. [4]

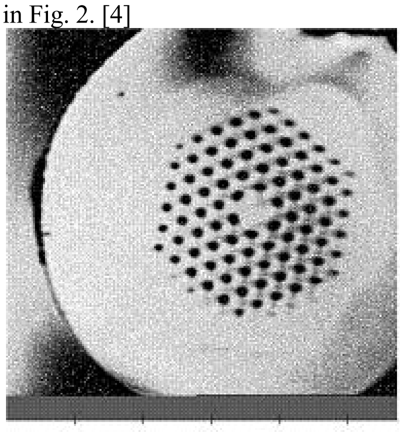

Figure 2 Cross-section of the investigated microstructured optical fiber of the second type obtained with atomic-force microscope

The classical fiber is a Corning SMF-28 optical fiber with the following parameters: silica core diameter is 8.2μm, silica cladding diameter is 125μm and protective coating diameter is 245μm. This fiber is the guiding structure for two radial modes at wavelength of 0.65μm.

The numerical computation of deformation and stress (effecting on the refraction index) of these optical fibers in case of one-sided loading was performed by the SolidWorks simulation package.

For calculation of the microstructured fiber of the 1-st type we used the following data: the number of finite elements– 175222, the number of nodes – 249873; for the 2-nd type microstructured fiber the number of finite elements – 164091, the number of nodes – 33117. At the modeling the scale was defined 10,000 times grater than the original ones. The applied force was equal to 1 N. So as the investigated loadings are located in the elasticity region the obtained strength growth is proportional to the applied force.

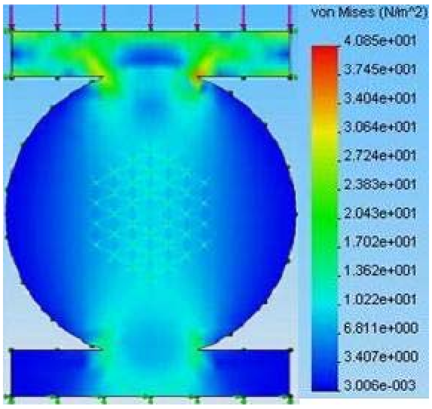

Figure 3 The first type microstructured fiber stress distribution in cross-section.

In the Figs. 3 and 4 the received stress distributions in the cross-section for the first and the second type fiber are presented.

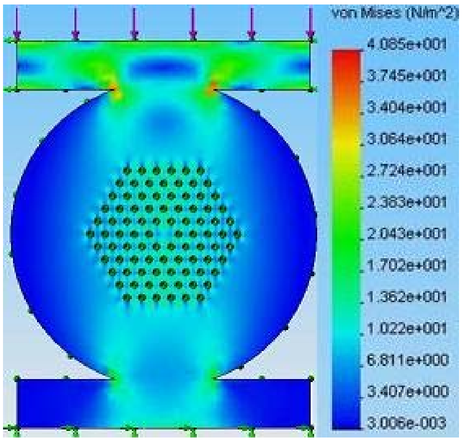

Figure 4 a The second type microstructured fiber stress distribution in cross section: loading at the angle of 120° to the facet of the hexagon of holes.

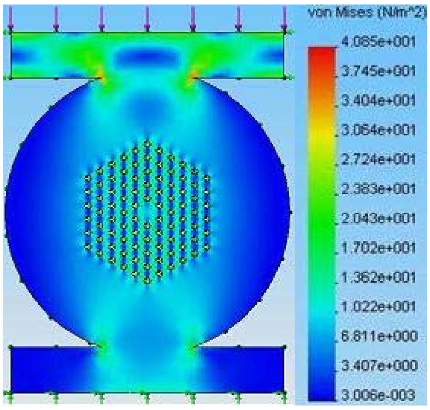

Figure 4 b The second type microstructured fiber stress distribution in cross section: loading at the angle of 90° to the facet of the hexagon of holes.

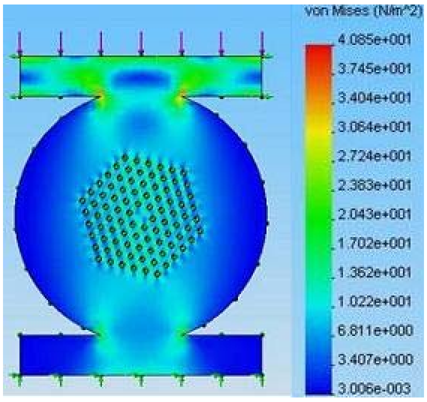

Figure 4 a The second type microstructured fiber stress distribution in cross section: loading at the angle of 105° to the facet of the hexagon of holes.

The obtained finite-element model demonstrates that in case of lateral compression the mechanical stress in the intermediate region of the cylindrical cavities forms an additional two-dimensional phase grating. It causes the losses of the radiation propagation in the optical fiber. Also the mechanical stresses create a phase grid both in the fiber core and in the region bordering on the cylindrical cavities location region. The Figs. 3 and 4 show the mechanical stresses caused in the core in the hole region at compression in case of the second type fiber are 2 times grater than in case of the first type fiber at the same loading.

The experimental investigation of the output signal dependence on the loading value for microstructured single-mode fibers and classical optical fibers was performed with the experimental set-up shown on the fig. 5.

Measurements were performed in the following way. Radiation of a semiconductor laser with a wavelength of 650nm was coupled with a microscope lens into investigated optical fibers and registered by optical powermeter. Microbends were induced with the transducer described above.

The loading was applied with preliminary calibrated spring.

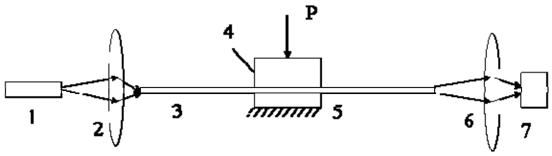

Figure 5 The experimental set-up scheme for investigation of the output signal dependence on the loading value in case of the microstructured and classical optical fiber. 1 — laser source; 2 — lens; 3 — optical fiber; 4 — pressure device; 5 — support; 6 — lens; 7 — photodetector.

Measurements data (Fig. 5) showed that the second type microstructured optical fiber has grater sensitivity to one-sided lateral compression against the first type MSOF, which in their turn is more sensitive against the classical Corning SMF-28 one.

The experimental data are approximated by the following functions (solid line):

$$OP = -0{,}0015F + 1{,}0068 \qquad (2)$$

(for Corning SMF-28);

$$OP = -0{,}0072F + 0{,}9881 \qquad (3)$$

(for the first type MSOF).

For the second type MSOF the solid line displays the average result for eight measurements.

The output signal dependence on the loading value for the first type MSOF is linear; for the second type MSOF – is quasi-linear. The classical Corning fiber signal decreases by only 5% at 45N loading, but for the first type MSOF – by 35%, respectively, i.e. the first type MSOF sensitivity to lateral compression is seven times grater than the classical one.

The Corning classical single-mode fiber signal decreases by 2% in average at 15N loading; the first type MSOF signal decreases by 50% correspondingly, i.e. the second type MSOF sensitivity to lateral compression is four times grater than the first type, and 25 times grater than the classical one.

So, the observed effect can be used in production of the amplitude (intensity) optical fiber force sensors.

III. RESUME

The received finite element model calculations show that while compression the mechanical stresses in the holes region form a volume phase grating, which causes the optical fiber radiation losses. MSOF and classical fibers as amplitude optical fiber sensor element was investigated. The experimental investigations showed that the sensitivity of MSOF with five layers of holes to lateral compression at 15 N loading is 4 times grater than the sensitivity of MSOF with three layers. The sensitivity of MSOF with five layers of holes to lateral compression at 15 N loading is 25 times grater than the sensitivity of a classical fiber. The sensitivity of MSOF with three layers to lateral compression at 45 N loading is 7 times grater than the sensitivity of the classical fiber.

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