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IMPACT OF RANDOM VARIATIONS OF AIR HOLE DIAMETERS AND RANDOM VARIATIONS OF THE CENTERS POSITION OF AIR HOLES ON OPERATION PARAMETERS OF A SOLID CORE MICROSTRUCTURED OPTICAL FIBER

A.I. Filipenko, A.N. Donskov
Kharkov National University of Radio Electronics, Kharkov, Ukraine
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Исследовано влияние случайного изменения диаметра включений и случайного изменения расположения центров включений на эксплуатационные параметры микроструктурированного оптического волокна с твердой сердцевиной, окруженной кольцом воздушных капилляров. Полученные результаты показывают, что при любом из рассмотренных видов дефектов модовое поле будет иметь два ярко выраженных максимума. Следовательно, при практическом использовании данного микроструктурированного оптического волокна необходимо производить угловое позиционирование торцов. Мы также показали, что случайное изменение диаметра включений может привести к увеличению полной мощности модового поля. В наших исследованиях мы использовали метод конечных элементов.
КЛЮЧЕВЫЕ СЛОВА: метод конечных элементов, распределение Гаусса, диаметр включений, полная мощность модового поля, угловое позиционирование, микроструктурированное оптическое волокно.

Досліджено вплив випадкового змінювання діаметра включень та випадкового змінювання розміщення центрів включень на експлуатаційні параметри мікроструктурованого оптичного волокна з твердою серцевиною, оточеною кільцем повітряних капілярів. Отримані результати свідчать, що при будь-яких з розглянутих видах дефектів модове поле буде мати два значно виражених максимуми. Тому при практичному використанні даного мікроструктурованого оптичного волокна необхідно проводити кутове позиціонування торців. Ми також показали, що випадкове змінювання діаметра включень може призвести до зростання повної потужності модового поля. В наших дослідженнях ми застосовували метод кінцевих елементів.
КЛЮЧОВІ СЛОВА: метод кінцевих елементів, розподілення Гауса, діаметр включень, повна потужність модового поля, кутове позиціонування, мікроструктуроване оптичне волокно.

We investigated the impact of random variations of air hole diameter and random variations of the centers position of air holes on operation parameters in the case of solid core microstructured optical fiber with a ring of air holes. The found results show that at any of considered defect types mode field will have two pronounced maximums. At practical use an investigated type of the MOF special angular positioning end faces of fibers is necessary. We also have shown that random variations of inclusions diameter can increase total mode field power. In our research we used finite-element method.
KEYWORDS: finite-element method, Gaussian distribution, inclusions diameter, total mode field power, angular positioning, microstructured optical fiber.

Microstructured optical fibers (MOFs) consist of dielectric materials (typically pure silica) with a regular array of air holes. There are two main categories of MOFs: fibers with a hollow core (HC) and with a solid core (SC). The SC MOFs are particularly interesting because have specific properties but without the fabrication and splicing difficulties encountered in the HC MOFs. Moreover, they also allow the photonic-bandgap (PBG) effect to be coupled with an actively doped SC and with the realization of wavelength-selective mirrors (Bragg gratings). These SC-MOFs are shown in Fig. 1.

The optical properties of these SC-MOFs depend on several main parameters that are listed as follows:

1) the index contrast Δn between the high-index inclusions and the silica background;

2) the diameter d of the high-index inclusions;

3) the ratio d/Λ, where Λ is the distance between the inclusion centers (pitch);

4) the vacuum wavelength λ of the excitation radiation. In this work we consider MOFs which consist of a silica core surrounded by a ring of air holes [1- 4].

Some defects are inherent to the fabrication process. One can mention, for example, the inhomogeneity of the initial germanium-doped preform: its diameter and refractive index evolve along its axis. The variation of the preform diameter induces a variation of both the diameter and the position of the inclusions when the hexagonal stack is assembled before drawing. These defects (and others) will lead to transverse disorders in the final fiber, which have to be taken into account in the model. [4]

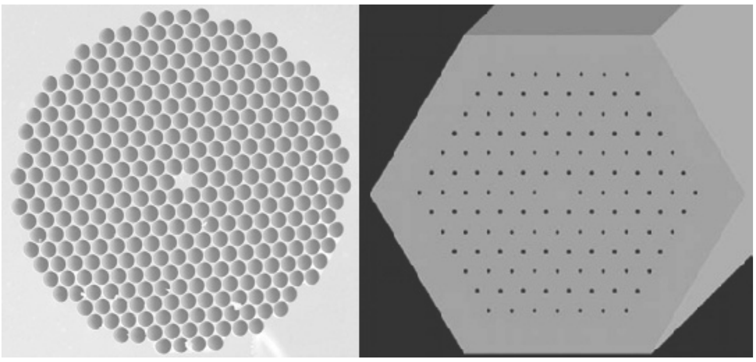

Fig.1. Transverse profile of SC-MOFs.

To investigate the impact of geometrical behaviors on operation parameters we use finite-element method [4, 5]. The main research tasks are listed as follows:

1) extraction of the mode field form in an investigated optical fiber;
2) definition of the mode field form variations both at a random variation of air hole diameters and at a random variation of the centers position of air holes;
3) calculation of total mode field power variations depending on variation of inclusion diameter.

The air hole diameter of an investigated fiber d = 1.6 μm and the distance between inclusion centers (pitch) Λ = 2.3 μm. We used wavelength λ = 1.55 μm. Transverse profile of an investigated MOF is shown in Fig. 2, as well as its mode field distribution.

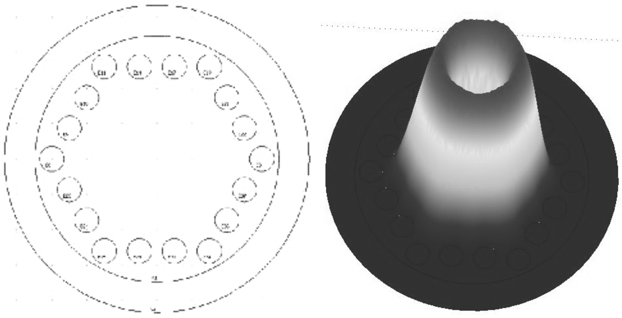

Fig.2. Transverse profile of the investigated fiber and its mode field distribution.

To define the mode field form variations both at a random variation of air hole diameter and at a random variation of the centers position of air holes we implement the effect of disorder first on one of two selected parameters, and then on two simultaneously: the air hole diameters and the positioning of air holes (for both transversal directions *x* and *y*). For each type of disorder we consider deviation in a range from –10% up to +10% of the Gaussian distribution that we use in order to generate the structures. Note that all the 18 air holes are subject to random perturbation. The results that we obtained are shown in Fig. 3

These three photographs show that at any of the considered defect types mode field will have two pronounced maximums even at insignificant variations of geometrical parameters. Results also have shown that position of maximums in relation to the center of symmetry of a fiber changes. It is evident that at practical use an investigated type of the MOF special angular positioning end faces of fibers is necessary.

To calculate total mode field power variations depending on variation of inclusion diameter first we implement the effect of disorder on air hole diameters (we consider deviation in a range from –10% up to +10% of the Gaussian distribution), and then we consider fixed deviation of ±5% and ±10% of all air hole diameters. In the first case we will consider total mode field power versus the mean diameter of air holes. Note that we will represent normalized values of total mode field power. The results that we obtained are shown in Fig. 4 and in Fig.5.

Results presented on fig. 4 show, that total mode field power increases with decreases of mean diameter of air holes. Another important result is that random variations of diameter of inclusions (air holes) can lead to an increase of total mode field power (when mean diameter of air holes is less than 1.6 μm).

Fig 5 shows, as expected, that computed total mode field power (normalized value) decreases when air hole diameter increases. This evolution can be interpreted as a consequence of the increase of the core diameter (effective area). Note that these results are in good agreement with the observations from Fig.4. Moreover, results of calculation of mean-square variation of inclusions diameter versus diameter of air holes show that at reduction of air hole diameter mean-square variation of total mode field power increases. Consequently, at reduction of air hole diameter spreading of the mode field in an investigated fiber is observed.

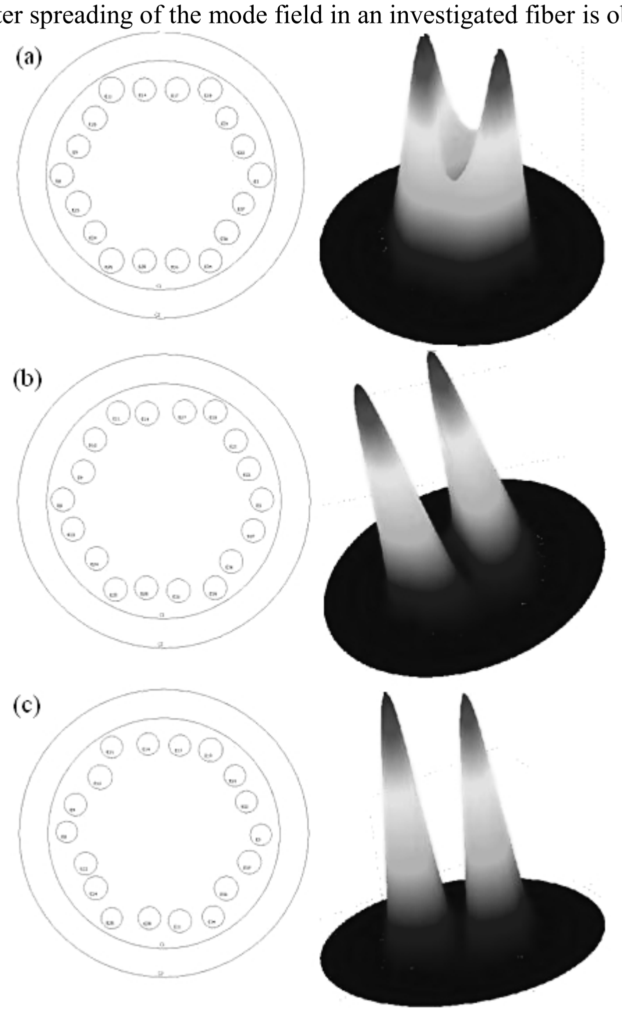

Fig.3. Transverse profiles of investigated fibers and their mode field distributions in three case of random variation: (a) of air hole diameters; (b) of the air hole position: (c) of two parameters simultaneously.

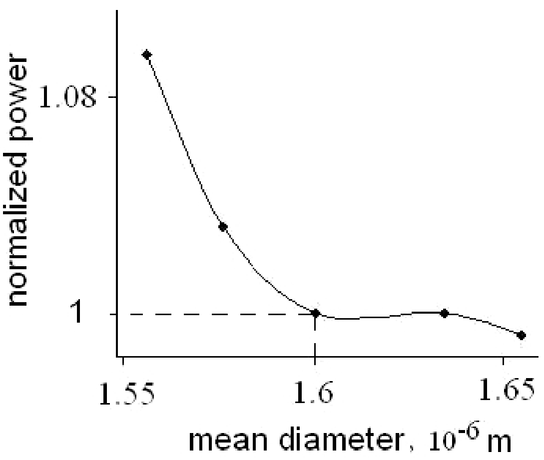

Fig.4. Normalized power versus the mean diameter of air holes

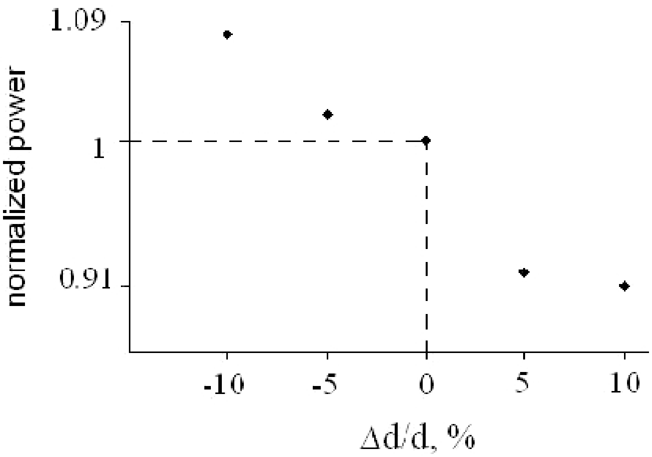

Fig.5. Normalized power versus the fixed diameter of air holes.

CONCLUSION

The found results show that at any of considered defect types mode field will have two pronounced maximums. Results presented in this work show, that total mode field power increases with decreases of mean diameter of air holes. Another important result is that random variations of diameter of inclusions (air holes) can lead to an increase of total mode field power At practical use an investigated type of the MOF special angular positioning end faces of fibers is necessary. We also have shown that random variations of inclusions diameter can increase total mode field power.

We believe that all presented results will be helpful for tolerance of fabrication processes and for better understanding of the role of random variation of geometrical behaviors (arising at fabrication processes) on operation parameters of microstructured optical fibers.

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