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OPINION
on the PhD Dissertation by Mr Hoang Van Thuy entitled „Optical Properties of Photonic Crystal Fibers Infiltrated with Liquids"

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This opinion of the doctoral dissertation has been prepared at the request of the Chairman of the Physical Sciences Discipline Council of the University of Warsaw, prof. dr hab. Zygmunt Lalak, expressed in the cover letter on the October 8th, 2020, attached to the dissertation.

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The description of the dissertation

The opinioned doctoral dissertation is 135 pages long. It consists of an abstract in English and Polish, a list of acronyms, 9 chapters, and references. The first chapter is an introduction, the second delivers the theoretical background on light propagation in photonic crystal fibers. There are descriptions of results of the modeling as well as experimental work in chapters from 3rd to 8th. The last part of the dissertation is a conclusion and presents the idea for the future work. The dissertation consists of a list of 161 references correctly selected references.

The scientific problem of the dissertation

There are three theses presented in this dissertation, which is under evaluation:

Thesis 1: *"Silica hollow core photonic crystal fibers infiltrated with liquids can offer flat all-normal dispersion regime in near-infrared range. The dispersion feature is compatible with central wavelength of commercially available femtosecond lasers for supercontinuum generation applications."*

Thesis 2: *"A broad spanning supercontinuum generation can be achieved in hollow core photonic crystal fibers with liquid infiltration and low peak power of input pulses."*

Thesis 3: *"Antiresonant fibers infiltrated with low-index liquids offer broadband transmission windows and are suitable for optofluidic systems."*

The first thesis of this dissertation has been correctly formulated and is an important and current scientific problem. It concerns the issue of tuning silica hollow core photonic crystal fiber dispersion by infiltrating them with liquids.

The second thesis of the dissertation presents a very interesting and up-to-date scientific problem. However, the thesis seems to be a little confusing because the power of the input pulse is indefinite and described as "low peak power". As a consequence, it is impossible to estimate the goal of the research work connected with this thesis precisely.

The third thesis of the dissertation is confusing as much as the second. I surmise that there should be "low-refractive index liquids" rather than "low-index liquids". On the other hand, the Author could consider other indices. However, the thesis lacks a precise description of this index. To make things more complicated in the second part of Thesis 3, there is a phrase:

"*are suitable for optofluidic systems*", which is imprecise and do not give any method to evaluate the achievement of the Author. In which case, the Author decides that the fiber is suitable. What does "*are suitable for optofluidic systems" mean*? Would it play a role of an optofluidic system or rather be used as a part of such a system? Such questions should not appear after reading the thesis, which should be formulated clearly and precisely.

Despite the fact, that Thesis 2 and 3 are described in imprecise way, all of the presented theses are important and current from the scientific as well as development point of view.

Critical state-of-the-art analysis

The dissertation includes the list of 161 references. Most of them are now-a-day papers. The theoretical background of the scientific problem is presented in the first chapter – "*Introduction*", and the second titled "*Theory of Light propagation in Photonic Crystal Fiber*". Despite the theoretical analysis of the problem, I have the impression that the Author focused on presenting the theoretical foundations repeatedly disscussed in other sources, but did not focus on an in-depth analysis of the current state of knowledge. Even if there are tables containing the parameters of optical fibers made in other research groups, they are not provided with comments focused on comparing their properties and on drawing conclusions. For example, data presented in Table 3.1 (page 39) are not commented on at all.

The part one in the Introduction - "*The Brief History of Optical Fiber*", Chapter 2.3.1 and 2.4 outline well known facts, which have been presented many times in literature before. Therefore, it seems to be redundant.

My main concerns are that the chapter "*Motivation and State-of-the Art*" is short and generic. In consequence after reading this chapter the motivation of the Author is still unknown.

Scientific problem

The author of the dissertation solved the scientific problems, which are described in Chapters 4 ÷ 8. These chapters contain the results of experimental work, simulation results and the comparison of simulated and experimental measurement data.

There are results of numerical modeling as well as results of the research work to prove Thesis 1 presented in Chapters 4, 5, 6 and 7.Thesis 2 is confirmed by the achievement presented in Chapters 6 and 7. Chapter 8 presents the results which prove Thesis 3.

In order to verify the theses, the Author of the dissertation conducted a series of research works, starting from numerical modeling, through designing and fabrication of the fiber structure. He designed and built optical set-up which was used to conduct the series of experiments, which verify thesis and numerical modeling. During these works, Mr. Hoang Van Thuy showed that he has the ability to plan and conduct research.
He solved the scientific problems and used an appropriate method to achieve the goal. The choice of the method, the Author used, for modeling as well as the choice of the configuration of the optical measurement system, which was built to verify the results of the theoretical simulation are correct.

Based on the analysis of the results, it can be concluded that the scientific problem presented in this dissertation have been solved.

Originality of the dissertation

Discussed issues are topical and the originality of the dissertation mainly lies in the development of the novel fiber optic elements, such as infiltrated photonic crystal fibers. Doctoral student demonstrates that the large core PCFs infiltrated with representative liquids can offer all-normal dispersion regime in near-infrared range. Furthermore, he proves that a broad spanning generation can be achieved in a hollow core photonic crystal fiber infiltrated by representative liquids. He also proofs that antiresonant fiber infiltrated with low-index liquids offer broadband transmission window.

Because of the fact that in the last two decades there was a rapid growth of the fiber optic technology and its application can be noted, there is still a need to design and elaborate new elements. From this point of view, this dissertation presents novel fiber optic elements, which can be used in fiber optic system like, for example, fiber optic measurement, imaging system (including microfuidic biomedical fiber optic systems dedicated to imaging or sensing).

It is worth noting that the developed fiber optic devices are compatible with the single-mode telecommunication fiber, which makes the elaborated infiltrated PCFs devices easy to use in fiber optic systems built from conventional elements.

The Author is a co-author of 9 articles published in journals from JCR journals with high impact factor. He is the first author in six of them, and the second in others. These articles are high cited in short period – the article [A1] has been cited 13 times from 2018 year when the article was published, and the paper [A2] - 9 times in one year. This proves

that the investigated topic is up-to-date and that the research conducted by the PhD student has been noticed. This proves as well that the Author has knowledge at an advanced level.

Comments and questions to the Author

Major comments

- Please outline your motivation for this work.
- A comparison of the parameters of many liquid core PCF and solid core PCF optical fibers is presented on page 121. The author of the dissertation presented a very short and cursory analysis of the results contained in the table, in which he did not present the reasons for including solid core fibers in the Table. Therefore, my question is, why are the solid core fibers' parameters listed in this table?
- In Figure 4.6. the deformation of the fiber tip can be noted. How do you handle this during measurements?
- The description of the air-holes fiber collapsing process is short. Please describe the process in more detail.
- As numerical modeling is a substantial part of this work, the description of modeling should be expanded and presented in more details, like conditions.
- Please present detailed parameters of used devices like an optical power meter, or sources – The Author presents usually only the central wavelength and time of the pulse.
- The manuscript lacks information on the selection process of source parameters. Please describe why do you use sources with those particular parameters (e.g. spectra width, spectra shape)?

  Additionally, describe the motivation for choosing the used liquids.

- There is a lack of the infiltration process description.
- What was and in which way was chosen the length between the lens and the spectrometer used in the set up for measurement SCG (Figure 5.5., page 75).
- According to the information that there was the combustion of the toluene at the end of the fiber, please estimate how long the measurement can be conducted?
  Can you propose any method to protect the fiber against this process?
- What does „*technical noise*" mean (page 86)?

- On pages 87 and 88the results of modeling and experiments are presented. However, it is impossible to compare them because the range of laser power used for summation is quite different from the user during the experiment. Please explain this.
- It can be beneficial to use the coefficient of determination ($R^{2)}$ to calculate the efficiency of the theoretical model.
- How do you estimate the position of the largest fringe in the Figure. 4.12., page 65?
- Can you present the parameters of elaborated elements in comparison to the commercially available or presented in the literature PCF elements?
- Please clarify what does it mean that the spectrum of AR fiber is not stable in the long –term.
- What does *„long term"* mean? What kind of changes in the spectrum have you noted?

Minor comments

1. The Author used many imprecise terms in this dissertation, which are improprieties in the description of physical and technical science. Between many others, there are some examples presented below:

- "When a commercial femtosecond laser was used as a pump source, the liquid core fibers offered supercontinuum (SC) spectrum in the near-infrared region and showed potential for coherence" (page i)
- "Antiresonant fibers infiltrated with low-index liquids offer broadband transmission windows and are suitable for optofluidic systems." (page 11)
- The Author often uses phrases: *"quite narrow"*; *"broad window"*; *"relatively small"*; *"relatively larger"*. It seems to be especially improper in the chapters, which summarize the results of modeling or measurements, where a thorough discussion of the results presented is expected (for example, the analysis presented on page 113).

2. Figure 2.2. (page 19) and Figure 2.3., Figure 2.4. 9 (page 18) lacks the description of the abbreviations, which are included in the presented graph. Furthermore, the Author uses a several colors in this graph and does not explain their meaning, excluding the orange line, which makes this graph unreadable. Therefore, in my opinion it would be more reasonable

to give references to articles, which include figures than to present figures without detailed description.

3. The lack of abbreviations, which are included in the figure or in the description. Even when the figure presents the original contribution of the Author of this dissertation (e.g., Figure 2.5., page 19; "MI noise", "the effect of MI", page 70).

4. In most cases, the quality of the presented figures is low (e.g., Figure 2.10., page 28) or too small to recognize details (e.g., 2.17., page 34; Figure 3.3., page 42; Figures 6.4. b ÷ e, page 82). Especially in cases when a self-made photo of the optical set-up is presented (e.g. Figures 3.3.b., page 42; Figures 3.6.b., page 46; Figure 3.9., page 49). The description of the set-up in the figures is unreadable as well or there is a lack of description of the presented photos.

In my opinion, those photos are redundant, because the schematic diagrams present the idea of the optical setup in a clear way.

5. There is the wrong numbering of the figures (e.g. Figure 6.9. is on page 88 and 91).

6. Other figures show commonly known devices like splicers and it is hard to understand the reason for including the photos of splicers in the dissertation.

7. Abbreviations used in Table 3.1 (page 39) lack the descriptions, which makes it difficult to analyze presented data.

8. The description of the optofluidic and temperature sensor should be shifted to future work, because only the idea of such sensors is presented.

9. The text needs English editing in many parts of the work.

Conclusion

The author of the dissertation proved all three theses presented in the doctorate. The reviewed work is a description of the original solution to a scientific problem by the author of the dissertation, as well as demonstrates his general theoretical knowledge in a scientific discipline and the ability to independently conduct scientific work. I confirm that the theses submitted for evaluation by Mr. Hoang Van Thuy meets the requirements of the Act on Academic Degrees and Academic Title.

Taking into consideration the achieved results and the legal regulations, I would recommend the Scientific Council of the Physical Sciences Discipline of the University of Warsaw to admit Mr. Hoang Van Thuy to further stages of his doctoral procedure.

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