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Re: Report on the Habilitation Thesis "*Selected properties of highly birefringent microstructured optical fibers*," by Dr. T. Martynkien

Dear Habilitation Committee

The subject of microstructured optical fibers (or photonic crystal fibers) is one of the topics intensively investigated within the scientific community. The interest is driven by their numerous applications in optical sensing, metrology, supercontinuum generation etc. This is evident from a vast number of scientific papers published annually and many international conferences devoted to this subject. One of the critical problems encountered in traditional as well as microstructured fibers is control of polarization of guided light. Isotropic fibers are prone to random polarization change due to environmental perturbations which hinders their application in sensing. The solution is to introduce strong birefringence into the fibers, hence ensure polarization maintenance through the fiber. Since first experiments in 2000, the subject of polarization maintaining (or highly birefringent) microstructured fibers has been a hot topic of best research groups around the word. The contents of this Thesis perfectly fit into this topic. It consists of ten articles published over the period of 2005-2018 in well recognized journals such as Optics Letters, Optics Express, Applied Physics B, etc. The thesis deals with selected aspects of highly birefringent microstructured fibers such as temperature and pressure sensitivity and their applications in hydrostatic pressure sensing, and nonlinear wave interaction. They form a quite coherent (except H7) set within the topic of photonic crystal fibers.

The publications cover three aspects of the subject:

- *Temperature susceptibility of modal birefringence in silica highly birefringent microstructured fibers (papers H1,H2,H3)*
- *The effect of hydrostatic pressure on modal birefringence of silica (H4,H5, H6) and polymer (H8-H10) highly birefringent microstructured fibers*
- *Nonlinear effects in silica highly birefringent microstructured fibers (H7)*

Dr. Martynkien prepared a very detailed guide for the papers entitled "Summary of Professional Accomplishments". The guide is excellently written providing important background information and summarizing main accomplishments. On the formal side though, I noticed few typos and some sloppiness in editing. For instance, some figures in the English version of the "Summary of Professional Accomplishments" contain labels in Polish. There is also part of text missing in the Polish version of the document. These are however minor points. The more severe issue is the missing paper H6 from the set of publications constituting the Thesis. The English version of the "Professional Accomplishments" appears there instead. This is a serious omission since this paper is a multi-author publication with the highest number of citations, and an authorship statement would help to determine the actual contribution of Dr. Martynkien.

Putting these formal issues aside we may concentrate on the technical side of the Thesis. The first three papers of the Thesis (H1-H3) are devoted to studies of the influence of temperature on the modal birefringence in silica microstructured fibers. The authors consider a few different designs and conduct extensive numerical studies of their temperature sensitivity. They showed that the geometry of fiber plays a crucial role in its temperature characteristic. They discover that for some choice of parameters the birefringence of the fiber is insensitive to temperature for a certain wavelength. By varying parameters of the fiber (i.e. arrangement of the holes) they showed that this wavelength may fall in the useful and readily available part of the spectrum. Further on, based on their calculations, authors fabricated a few types of microstructured fibers and investigated their temperature characteristics. They demonstrated experimentally, for the first time, the temperature insensitivity for certain wavelength (papers H2, H3). This result is extremely important from a practical point of view as it would simplify the construction of sensors based on such fibers as they would be immune to temperature variation.

The next publications (H4-H6) are concerned with the application of high birefringent fibers as hydrostatic pressure sensors. In the H4 paper authors investigate theoretically the influence of pressure on phase and group modal birefringence. They showed that the pressure induced stress is mostly responsible for changes of modal birefringence. They proposed fiber design with increased pressure sensitivity. In subsequent papers (H5, H6) they implement their earlier results and designed microstructured fiber which was expected to be highly sensitive to hydrostatic pressure and, at the same time, be temperature insensitive. They fabricated such fibers and investigated experimentally their pressure and temperature characteristics. They showed that designed fiber exhibited pressure sensitivity twice of the earlier published, with low temperature sensitivity. This is a very encouraging result showing the possibility to further improving performance and proves deep understanding of the subject and ability by Dr. Martynkien to accurately model the fiber behavior.
This is confirmed further in the subsequent paper (H6), in which authors achieved even better result. They designed and subsequently fabricated novel microstructured fiber with low temperature sensitivity, which exhibited fivefold increase of hydrostatic pressure sensitivity, compared to earlier published results. Incidentally this fiber featured germanium doped core so it could have UV-written Bragg gratings inscribed in it for grating based sensing. This result is a pinnacle of Dr. Martynkien's research devoted to application of structured fiber in pressure sensing. It proves excellent understanding of the subject from theoretical point of view as well his capability to convey theoretical results in real design. Great outcome widely appreciated by optics community as evident by citation record.

The experience gained from successful works on silica highly birefringent microstructured fibers has been subsequently employed by Dr. Martynkien and colleagues in studies of polymer photonic crystal fibers (H8-10). These fibers constitute valuable alternative to silica fibers, in some applications, thanks to their low processing temperature, and good mechanical properties including high flexibility in bending, non-brittle nature, as well as compatibility with organic material.
In the first paper (H9) authors successfully demonstrated fabrication of birefringent PMMA fiber where birefringence was achieved via stress field caused by polystyrene rods in the cladding. Very good and apparently a world first result.

In subsequent two publications (H8, H10) Dr. Martynkien and colleagues investigated the applicability of polymeric microstructured fiber for hydrostatic pressure sensing. First, they numerically analyzed properties of the in-house fabricated polymeric highly birefringent microstructured fiber with enlarged holes in the cladding to enhance fiber sensitivity to hydrostatic pressure. Simulation did indicate high sensitivity of the fiber to pressure. In the last paper (H10) they demonstrated experimentally the pressure sensitivity of simple design of side holes polymeric fiber. They showed that sensitivity is directly related to the thickness of the distance between the two holes and can be as high as in specialized silica microstructured fibers optimized for pressure sensing. Again, very good world class result.

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Finally, there is the H7 paper of the Thesis. In this work authors employed their polarization maintaining fibers in a simple nonlinear optical system which operated as a tunable source of ultrashort pulses. To this end they used Raman-induced soliton self-frequency shift in their own design of germanium core highly birefringent fiber and subsequently generated sub 100fs pulses. In terms of energy their system outperformed those previously reported in the literature. This is an excellent result. However, I am not sure why Dr. Martynkien decided to include this paper as its subject stands out of that covered by all other papers. Furthermore, as I understand, Dr. Martynkien was not an initiator nor the leader in this project. Perhaps he wanted to demonstrate versatility of his scientific interest.

In summary, the Thesis of Dr. Martynkien constitutes excellent research addressing and successfully solving challenging and innovative scientific problems. The agreement between theory and experiment shown in enclosed publications is amazing. This is proof of Dr. Martynkien's in-depth understanding of analyzed phenomena. The papers significantly advance knowledge in the field of microstructured fibers and provide outcomes with direct implications for further development and practical applications. While all these papers represent joint works, it seems Dr. Martynkien played a pivotal role in majority of them. This is confirmed by contribution statements from all co-authors. Even though he is not listed as a first author in H4, H5 and H7 papers, he evidently made significant contribution to the theoretical modelling and experiments. In most of the enclosed papers, he appears clearly as an instigator and leader of the projects setting the aims and actively contributing with numerical modelling as well as conducting experiments.

The Thesis confirms capability of Dr. Martynkien to initiate, lead and carry high quality innovative research projects. The combination of theory and experiment is especially invaluable as it provides immediate verification of theoretical models, allowing e.g. optimization of final photonic fiber structure. Furthermore, the Thesis proves Dr. Martynkien's ability to efficiently collaborate with a versatile team of scientists from domestic and international groups.

It is my opinion, that the Thesis of Dr. Martynkien represents outstanding research work with considerable impact in the field. Therefore, the Thesis significantly exceeds the requirement for earning Dr. Martynkien degree of habilitated doctor. I sincerely congratulate him on his achievements and wish him successful research in the future.

Yours sincerely

W. Krolikowski

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