Research Trip Summary Report

Task 2. Foreign mobility of WUST doctoral students

I. Data of the doctoral student

1.Full name: Karolina Stefańska

2.Year of studies: 4.

3. Educational discipline: Physical Sciences

II. Foreign research trip (research visit)

1. Research institute in which the foreign research was implemented: Laboratoire Interdisciplinaire Carnot de Bourgogne (UMR6303 CNRS-Université Bourgogne Franche-Comté), Dijon, France

2. Name and surname of the host person (mentor): Dr Bertrand KIBLER

3. Dates of the research trip: 04.09.2023 - 06.10.2023

4. Title and date of a seminar delivered during the research trip:

“Experimental observation of discretized conical wave in a multimode fiber”, 14.09.2023

5. Description of work carried out during the research trip:

The works carried out during the research trip can be divided into two main parts.

The first part concerned carrying out the experiments related to demonstration of helicon wavepackets emerging during nonlinear propagation of pulses in step-index multimode optical fiber. The existence of this special wavepacket was earlier theoretically predicted and studied numerically by Bertrand Kibler and Pierre Béjot from the hosting institute, who simulated the helicon wavepacket generation during nonlinear propagation of femtosecond laser pulses at 800 nm [1,2].

In the experiments carried out during the research trip, I used a laser source which emits 275 fs, 1035 nm pulses with a repetition rate of 10 kHz. The laser beam was shaped using the combination of polarizers, half- and quarter-wave plates, and vortex plate. Then, I tested various plano-convex lenses in order to optimize the size of the focused beam to best fit the calculated size of the fiber modes. I also developed the part of the setup to characterize the spectral and spatial components of the fiber output.

By controlling the angle of the axis of the wave plates, I studied different excitation conditions:

- Pure excitation of the lowest order OAM mode of the fiber, that carries topological charge l=1;
- Excitation of superposition of the above mode with the fundamental mode of the fiber.

The pure excitation of the fundamental mode has been investigated earlier during my PhD and recently published [3].

I performed the first experiments in the linear regime, using low power levels of the input beam. Using optical spectrum analyzer and a CCD camera, I investigated how the modal composition of the input beam affected the fiber output spectrum and intensity distribution. Next, I studied nonlinear propagation of the beam using increasing power levels of the injected beam. Using my experience from my previous investigations of the discretized conical emission in multimode fiber, I could recognize the signature of the emergence of helicon wavepacket and link it to the spectral broadening and appearance of a "spectral shoulder" in the short wavelength range of the supercontinuum. I indeed observed such behavior when exciting superposition of the two fiber modes. However, during exciting the superposition of the two fiber modes, it is worth mentioning that the peak power levels necessary to observe this process were higher than in the case of excitation of the fundamental mode of the fiber. Such power levels, close or even exceeding the critical peak power for beam self-focusing, may be also close to some damage thresholds of the fiber, thus leading to severe instabilities of wave propagation during the experiment. Due to stability issues of the measured signals at the fiber output, part of the planned works concerning interferometric measurements of output spatial phase could not be carried out. During pure excitation of the OAM mode, the power level required to reach the spectral broadening was even much higher than in the latter case, which also lead to damage. Such instability issues related to breakdown threshold and nonlinear absorption could not be accounted for in the previously performed numerical simulations. To avoid this, one possibility would to operate at another wavelength to decrease the required peak power, where the fiber exhibits lower dispersion, however this would require new equipment, in particular a specific vortex plate, and check the beam quality delivered by the optical parametric amplifier that can be used with the pumping laser. However, the experiments performed during the research mobility showed that in practice, clear signatures of discretized conical emission can be observed even when using higher order OAM modes of the fiber. A detailed characterization of helicon wavepackets would require a deeper analysis and design of the whole experiment.

The second part of the research mobility concerned experimental works related to orbital chirality of light in isotropic inhomogeneous medium, more specifically cylindrically-symmetric optical fiber. Although this part of the mobility was not planned initially, the idea conceived by Pierre Béjot and preliminary numerical results seemed a promising perspective of multimode fiber research, worth to be explored experimentally in the remaining time of the stay. To do this, I prepared a setup using a 1064 nm, 400 ps laser source and a combination of polarizers and waveplates (half-, quarter-, and vortex plate). After shaping the beam polarization, and spatial intensity and phase, I could control the excitation of a specific combination of OAM modes in a few-mode step-index fiber. At the fiber output, I analyzed the polarization and spatial intensity distribution with a camera and a power meter as a function of propagation distance by performing cutback measurements.

Doing so, I explored the spin-orbit couplings of light in two experiments to show how orbital angular momentum influence on the trajectory and polarization of light. I experimentally demonstrated the following effects:

- OAM-based circular birefringence;
- Helical birefringence.

The obtained results agree very well with theoretical predictions and numerical simulations.

In conclusion, most of the internship research program was successfully accomplished. Investigating the possibility of experimental generation of helicon wavepackets during nonlinear pulse propagation in a multimode fiber is an important contribution to the realized PhD thesis which is devoted to nonlinear phenomena in multimode fibers. Furthermore, the experiments realized during the second part of the stay, and performed beyond the initial research plan, are a significant contribution to the research in the field and will result in the publication in a near future.

[1] P. Béjot, and B. Kibler, ACS Photonics, 8, 2345-2354, 2021
[2] P. Béjot, and B. Kibler, ACS Photonics, 9, 2066–2072, 2022
[3] K. Stefańska, P. Béjot, K. Tarnowski, and B. Kibler, ACS Photonics, 10, 727-732, 2023

6. Description of the main results obtained:

The research mobility resulted in the following two main results:

- investigating the limitations in generation of helicon wavepacket in multimode fiber;

- demonstration of circular birefringence and helical optical activity induced by spin-orbit couplings in cylindrically-symmetric few-mode optical fibers.

Based on the results obtained in the second part of the research mobility, a publication in a scientific journal is currently being prepared.

7. Future collaborations (if applicable):

Analysis of the results obtained during the research trip and preparation of a scientific publication.

8. Title and date of a seminar presenting the results of the trip delivered at Wroclaw University of Science and Technology after returning from the research trip:

“Experimental studies on helicon wavepackets and spin-orbit coupling of light in optical fibers” – 14.11.2023, Seminarium Optyki Stosowanej seminar.

III. Doctoral student's signature

…….. (Date)

……. (doctoral student's signature)

IV. Confirmation and information from the host

1. Confirmation of compliance of the information contained in the report: I CONFIRM / ~~DO NOT CONFIRM~~. (*In justified cases, the confirmation of the host may be sent by e-mail to the Dean's Office of the Doctoral School email: interdocschool@pwr.edu.pl*)

2. Additional information and comments

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(Date)

(signature(s) of Host)