Warsaw, 30.11.2021

Mattia Longobucco
Wydział Fizyki
Uniwersytet Warszawski

ABSTRACT OF THE DOCTORAL DISSERTATION

Study of solitonic steering of femtosecond pulses in soft glass dual-core optical fibers

In this dissertation, a study of pulse energy-controlled solitonic steering of femtosecond pulses in highly nonlinear dual-core fibers is presented. It targets a specific area of ultrafast nonlinear fiber optics and also the general soliton theory in coupled waveguides, with high application potential in all-optical signal processing. The goal of the dissertation is to prove that specially designed dual-core fibers made of soft-glass materials support an energy-driven switching of femtosecond pulses. The fiber is made of a pair of two thermally matched glasses: a lead silicate (highly nonlinear) and borosilicate glasses for the cores and cladding, respectively. They have high contrast of the refractive indices at the level of 0.4 in the near infrared. The physical principle that allows the switching performance is the nonlinear self-trapping of high-order solitons, which is induced by the nonlinear Kerr effect in the core glass.

The first part of the dissertation shows the numerical study of the fiber structure optimization in terms of its dispersion and coupling properties. Two alternatives are studied: all-solid photonic crystal dual-core fiber and all-solid dual-core fiber with homogeneous cladding. Then, the numerical simulation results of the nonlinear propagation of femtosecond pulses with energies in the picojoule range are presented. The goal is to determine the wavelength and temporal width of hyperbolic secant pulses which support the optimal switching performance. They are in the range 1400 - 1800 nm and 75 - 150 fs, respectively. The optimal switching performance is identified in terms of highest switching contrast parameter, which indicates the capability of the excited pulse to exchange core during propagation. The optimal switching performance is predicted for a 43 mm all-solid dual-core fiber with simple cladding and 3.2 μm distance between the cores. The excitation pulses have 1500 nm wavelength, 75 fs temporal width and in-coupled energies at the level of only 20 pJ. The highest switching contrast is 46 dB calculated in the time window of the ultrashort pulses. Moreover, the predicted switching performance is uniform over 200 nm in the spectral domain. Afterwards, the dissertation proceeds with a brief description of the fabrication process of the optimized dual-core fiber. It is based on the stack-and-draw method. Then, the structure of the fabricated fiber is analyzed in terms of dual-core asymmetry. It is related to the difference between the shapes of the two cores. It is always present after the fabrication process because of the intrinsic thermodynamic fluctuations of the drawing parameters. Therefore, its influence on the coupling properties of the fiber, on the ultrafast pulse propagation, as well on the switching performance, is examined.

The second part of the dissertation presents the experimental results of self-switching, i.e. energy-driven nonlinear switching, using femtosecond pulses at wavelength of 1560 and 1700 nm. Two sets of all-solid dual-core fibers with the optimized structural parameters and different levels of dual-core symmetry were used. The following outcomes were demonstrated: 1) reversible switching performance of 1560 nm sub-nJ pulses, with soliton-like character

(confirmed by numerical simulations); 2) switching performance at 1700 nm of pulses with 1-3 nJ input energy; it shows a two-time exchange of the core with a maximal switching contrast of 16.7 dB and it is broadband in a spectral window of 150 nm. In the frame of the study of the fiber length effect, the highest switching contrast of 20.1 dB at 35 mm fiber length is demonstrated at 1560 nm. The switching performance is observed in a broadband spectral range between 1450 and 1650 nm. In the case of 1700 nm excitation wavelength, the highest switching contrast is 20.6 dB at 40 mm. It is accompanied by multiple exchanges of the dominant core, which is a strong indication of the soliton-based switching process. Both reported outcomes rely on the lower dual-core asymmetry of the all-solid fiber than the one of the standard air-hole dual-core fiber, which was investigated previously.

Finally, in the last part of the dissertation a novel switching approach is presented: the so-called dual wavelength approach. It is based on the cross-interaction between two synchronized femtosecond pulses with different wavelengths: *signal* (1560 nm) and *control* (1030 nm). The adjustment of the control pulse energy enables the signal pulse to switch between the cores. The novel switching approach is based on the physical process of nonlinear balancing of dual-core asymmetry: the control pulse induces a group velocity reduction of the signal pulse, which finally switches between the cores. Switching contrasts of more than 25 dB and a shift of the signal central wavelength of only 3 nm were recorded using fibers with optimized lengths below only 20 mm. These results were confirmed also by the spectra recordings at the fiber output.

Thanks to the improved dual-core symmetry, the fiber design without microstructure and fabricated with the all-solid approach allows an efficient switching capability of optical soliton-like pulses. Moreover, it can have some practical applications in optical communications as fiber-based, low-power, compact and simple all-optical switching device.