Spatio-temporal multiplexing based on multi-core fiber

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Switching of light between temporal and spatial domains have a range of applications from telecommunications to coherent pulse combining. For instance, in laser applications in manufacturing and high-definition design of complex properties in materials, the surface of the treated metal product is exposed to a sequence of high-power optical pulses with certain period in time, where each pulse is focused onto some spatial point in the product surface. Various schemes of linear beam/pulse combining are used to generate a high power optical beams [1]. An important requirement in coherent beam combining is the precise phase control of the input beams to maintain the output pulse coherence. Previously, we have demonstrated the possibility of using nonlinear effects in multi-core fibers (MCF) for the combining and compression of optical pulses [2]. It was observed that in the MCF based approach, the requirements on the phase control can be weakened. Unlike conventional optical switch schemes [3], here we vary the input signal parameters, while the characteristics of the fiber remain fixed.

In this paper, we demonstrate the design rules for nonlinear combining of high-power optical pulses at consequently selected core of MCF with two-dimensional circle arrangement of the cores, slightly resembling a pan magazine in the machine gun, in a sense that pulses appear one by one in the consecutive cores. The considered device makes multiplexing between temporal position of pulses into spatial domain. While it has been shown in previous studies the pulse combining in the central core [3], here we show when it is possible to effectively combine the optical pulses in any core by adjusting the parameters of the input pulses.

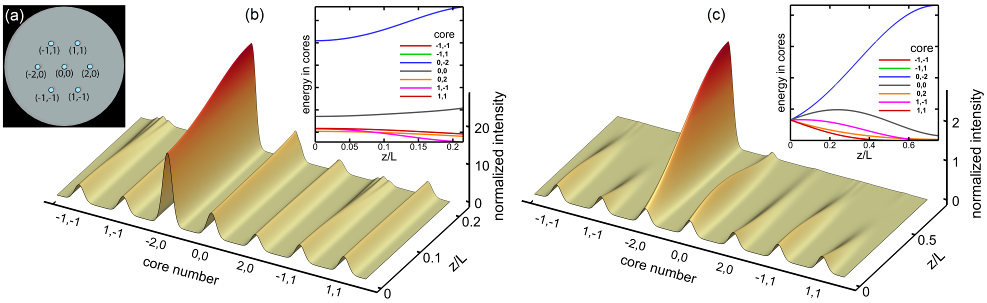

Fig. 1 Scheme of considered 7-core hexagonal multi-core fiber (a). Pulse intensity dynamics and the energy by cores (insets) for the solutions obtained by the genetic algorithm: using modulation of amplitudes (b) and using phase adjusting (c).

Here we use as an example a 7-core hexagonal MCF (Fig. 1a). The discrete nonlinear Schrödinger equation was used for the propagation simulation along MCF, while the genetic algorithm (GA) was used for parameter optimization. In the GA the vector of input Gaussian pulse parameters (amplitudes, widths, and phase chirps) played role of a genotype of each individual in the population. The maximum pulse combining efficiency was assigned as the value of the fitness function for each individual. We have considered two approaches to determining the Gaussian pulse parameters under which the combined pulse can be obtained in one of the peripheral cores.

The first approach is easier for practical realization and it assumes that all pulses have equal parameters and only amplitudes differ. Using GA we have found that if the amplitudes of the input pulses differ from each other by: not more than 2 times, the maximum achievable pulse combining efficiency is 28%; more than 5 times (see Fig. 1b), the maximum efficiency is 53%; 10 times difference results in the maximal efficiency about 69%.

The second approach requires a control of the initial phases of the pulses. We set input pulses amplitudes, widths and chirps to be equal, but change the phase of each pulse, and thereby maximize the pulse combining efficiency in the peripheral core.As a result, by using the GA the pulse parameters were obtained giving combining efficiency about 95% (Fig. 1c). Numerical analysis of the influence of the fluctuations of initial pulse phases showed that obtained regimes of both the first and second approaches have sufficient stability margin.

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References

[1] M. Hanna, *et. al.*, Journal of Physics B: Atomic, Molecular and Optical Physics **49**, 062004 (2016).

[2] I. S. Chekhovskoy, *et. al.*, Phys. Rev. A **94**, 043848 (2016).

[3] J. Zhou, Opt. Express **23**, 22098-22107 (2015).