IOP Publishing Journal of Optics
J. Opt. 23 (2021) 015501 (11pp) https://doi.org/10.1088/2040-8986/abcc57

Spatiotemporal solitons in dispersion-managed multimode fibers

Thawatchai Mayteevarunyoo[1], Boris A Malomed[2,3] and Dmitry V Skryabin[4]

[1] Department of Electrical and Computer Engineering, Faculty of Engineering, Naresuan University, Phitsanulok 65000, Thailand
[2] School of Electrical Engineering, Faculty of Engineering, Tel Aviv University, Tel Aviv 69978, Israel
[3] Instituto de Alta Investigación, Universidad de Tarapacá, Casilla 7D, Arica, Chile
[4] Department of Physics, University of Bath, Bath BA2 7AY, United Kingdom

E-mail: thawatchaim@nu.ac.th

Received 30 July 2020, revised 21 October 2020
Accepted for publication 19 November 2020
Published 11 December 2020

Abstract
We develop the scheme of dispersion management (DM) for three-dimensional (3D) solitons in a multimode optical fiber. It is modeled by the parabolic confining potential acting in the transverse plane in combination with the cubic self-focusing. The DM map is adopted in the form of alternating segments with anomalous and normal group-velocity dispersion. Previously, temporal DM solitons were studied in detail in single-mode fibers, and some solutions for 2D spatiotemporal 'light bullets', stabilized by DM, were found in the model of a planar waveguide. By means of numerical methods, we demonstrate that stability of the 3D spatiotemporal solitons is determined by the usual DM-strength parameter, S: they are quasi-stable at $S < S_0 \approx 0.93$, and completely stable at $S > S_0$. Stable vortex solitons are constructed too. We also consider collisions between the 3D solitons, in both axial and transverse directions. The interactions are quasi-elastic, including periodic collisions between solitons which perform shuttle motion in the transverse plane.

Keywords: spatiotemporal soliton, dispersion management, non-linear optics, multimode optical fibers

(Some figures may appear in colour only in the online journal)

1. Introduction

Multidimensional solitons represent a vast research area comprising optics, Bose–Einstein condensates (BECs) in ultracold gases, plasmas, liquid crystals, and other areas [1–11]. A fundamental problem is that the ubiquitous self-focusing cubic non-linearity, represented by the Kerr term in optics [12] or the collisional one in the Gross-Pitaevskii equation for self-attractive BEC [13], creates two- and three-dimensional (2D and 3D) solitons which are unstable because the same cubic terms give rise to the critical and supercritical collapse in 2D and 3D, respectively [14]. One possibility for the stabilization of 3D matter-wave solitons in BEC, including ones with embedded vorticity [15], is the use of the trapping parabolic, alias harmonic-oscillator (HO), potential [16], which is, in any case, a necessary ingredient in the experimental realization of BEC [13]. A qualitatively similar mechanism helps to stabilize 3D 'optical bullets' [17] (spatiotemporal solitons) in multimode optical fibers, i.e. ones defined by the radial pattern of the graded (refractive) index (GRIN) in the transverse cross-section plane. Such fibers have been a subject of fundamental and applied research since long ago [18–21], due to their potential for the use in optical sensors [22, 23], high-speed interconnects [24, 25], and space-division multiplexing [26–28]. The GRIN structure, supporting many transverse modes (see, e.g. [29]), makes it possible to consider 3D solitons as non-linear superpositions of such modes, self-trapped in the temporal dimension, i.e. along the fiber's axis [30–34]. Recently, this approach to the study of spatiotemporal solitons has drawn much interest [35–44].

Another method for stabilization of both one- and multidimensional solitons, in the form of oscillating breathers, with an intrinsic *phase chirp* [12], is provided by 'management' techniques. They are represented by periodic modulation of

