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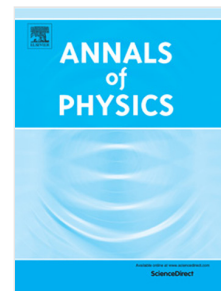
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Butterfly-shaped and dromion-like optical waves in a tapered graded-index waveguide with variable group-velocity dispersion

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Abstract

Butterfly-shaped and dromion-like optical waves in a tapered graded-index waveguide (GRIN) are reported for the first time. The generalized nonlinear Schrödinger equation, which describes wave propagation in GRIN with variable group-velocity dispersion (GVD), nonlinearity, $\mathcal{PT}$ symmetric optical potentials, is investigated and analytical solutions for this dynamical system are obtained. The physical effects affecting these waves are explicated in detail. The stability of dromion-like structures is analyzed when the GVD parameter is perturbed. We have observed oscillation structure exhibiting strong interference due to this applied perturbation. For a particular value of the modulation of the GVD parameter, the oscillation structure is transformed into two dromion-like structures. It indicates that the dromion-like structure is unstable, and the coherence intensity is affected by the modified perturbation parameter. We further demonstrate the phenomenon of unbreakable $\mathcal{PT}$ symmetry of these novel nonlinear waves for three explicit examples.

1. Introduction

Solitons are localized particle like structures which appear due to interplay between nonlinearity and dispersion. They have ample applications in many fields of science such as nonlinear optics, condensed matter physics, biology, chemistry, fluid dynamics, plasmas etc.[1, 2, 3, 4, 5, 6, 7, 8]. Optical solitons in lossless fibers were theoretically predicted first by Hasegawa and Tapert [9]. Since an optical soliton is a stable pulse and can represent an elementary bit, it has many features that makes it attractive for transmission, storage and processing of digital information. Solitons can be managed through different choices of dispersion and nonlinearity. One such new kind of soliton pulse called butterfly-shaped pulse was first investigated by Wen et al. [10] in optical fibers with variable group velocity dispersion (GVD) and constant Kerr nonlinearity. Later, interactions between these pulses which affect the pulse propagation qualities were described [11]. A variant of nonlinear Schrödinger equation (NLSE) which is a foundational model in the field of nonlinear science is used to study such solitons. Moreover, another type of localized coherent structure called dromion having the property of decaying exponentially in all directions [12] has been obtained for the same model [13]. Recently great progress has been made to study dromions [14, 15, 16, 17, 18]. These dromion structures have been studied for (2+1) dimensional variable coefficient NLSE (vc-NLSE) with $\mathcal{PT}$ -symmetric potential [19]. To our knowledge, butterfly-shaped and dromion-like optical waves in a tapered graded-index waveguide having unbreakable $\mathcal{PT}$ symmetry are analyzed for the first time. Previously, optical similaritons in a tapered graded-index waveguide have been explored [20, 21, 22, 23].

The concept of $\mathcal{PT}$ symmetry in quantum mechanics was first introduced by Bender et al. [24] according to which a wide class of non-Hermitian Hamiltonians exhibit entirely real eigenvalue spectra provided they respect parity-time ($\mathcal{PT}$) symmetry. In quantum mechanics $\mathcal{PT}$ symmetry dictates that potential should satisfy the condition $V(x) =$

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