ANNOTATION OF MATERIALS

under art. 65 of the Regulations for the development of academic staff of Plovdiv university "Paisii Hilendarski"

of

Ch. Assistant Professor Aneliya Mincheva Dakova-Mollova, Ph.D

for participation in a competition for the occupation of an academic position "Associate professor" in the field of higher education 4. Natural sciences, mathematics and informatics, professional field 4.1. Physical Sciences (Physics of Wave Processes) at the Faculty of Physics and Technology of PU "Paisii Hilendarski", announced in the State Gazette, issue 96 from Friday, 17.11.2023.

The publications submitted for participation in the competition for the academic position of “Associate Professor” were developed after obtaining the degree “PhD” and after acquiring the academic position of “Chief Assistant Professor” and include 25 publications.

- All publications for the competition are in journals that are referenced and indexed in world-renowned databases with scientific information (Web of Science and/or Scopus).
- The main scientific topics of the candidate's publications presented in the competition are aimed at searching for analytical solutions of nonlinear differential equations and determining the initial conditions of laser radiation and the medium, necessary for the formation of optical solitons, optical vortex structures, observation of four-photon parametric processes and energy exchange between light pulses and their components in nonlinear dispersive media.
- 25 publications are presented, of which 15 have IF (with a total IF of 38.67) and 10 have SJR.
- *h*-index 8 (according to Scopus)

Source: SCOPUS (11.01.2024)

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Articles

- **<u>According to criterion B4</u>: Habilitation thesis - scientific publications in journals that are referenced and indexed in world-renowned databases with scientific information (Web of Science and Scopus):**

B4-1. <u>Aneliya Dakova-Mollova</u>, Pavlina Miteva, Diana Dakova, Valeri Slavchev, Zara Kasapeteva, Tsonyo Pavkov, Lubomir Kovachev, Broad-band optical solitons, Optik, Volume 279, 170770, (2023), ISSN 0030-4026, https://doi.org/10.1016/j.ijleo.2023.170770, **SJR(2022)=0.539, IF(2022)=3.1, (Q2)**.

<u>Abstract</u>

Current research is devoted to the study of the regimes of propagation of broad-band laser solitons with femtosecond or attosecond duration in isotropic nonlinear dispersive media such as single-mode optical fibers. Developments in this direction have been highly relevant in recent decades due to the increasing use of ultra-short laser technologies, where the optical pulses have duration of *5 - 6 fs*, in scientific researches, which are not only of fundamental importance, but find application in various areas of public life, such as telecommunications, industry, medicine and many others.

In this article it was investigated analytically and numerically the evolution of broad-band laser pulses in single-mode fibers when the dispersion of the medium is anomalous and normal. It was shown that, under certain conditions in such waveguides, bright and dark solitons can be observed. New exact solutions of the nonlinear amplitude equation (NAE) were obtained in the form of periodic cnoidal wave (Jacobi elliptic functions). For fixed value of the modulus of ellipticity $\kappa \rightarrow 1^-$ they are reduced respectively to bright or dark soliton. It is important to mention that the found solutions are different from the standard soliton solutions of Nonlinear Schrödinger equation (NSE) in the case of optical pulses with broad-band spectrum only. They lead to a new kinds of nonlinear dispersion ratios, in which it is involved additional dimensionless parameter (α), connected with nonparaxiality of the theoretical model. It significantly affects the modulus of ellipticity κ.

It is important to note that the nonlinear phase of the broad-band fundamental solitons results in an addition to the group velocity that leads to a shift of the pulse peak. A significant difference is observed in the case of bound multisoliton states. It is numerically observed for broad-band multisoliton pulses a decay and a new type of bound state between the solitons.

Femtosecond optical pulses are widely used in fields such as micromechanics and electronics, nanotechnology, photochemistry, imaging, laser light therapy in medicine and dentistry, precision laser surgery, optical communication systems, LIDAR systems for probing the upper layers of the atmosphere, generation of THz and GHz frequencies and many others. This necessitates a thorough study of the effects related to the peculiarities in the dynamics of ultra-

short optical solitons with broad-band spectrum. The results of the study of the evolution of one-dimensional and three-dimensional ultra-short laser pulses can be used for the more complete and correct description of their behavior in isotropic solid, liquid and gaseous media.

The candidate's personal contribution consists of the analytical calculations for finding solutions of NAE in the case of bright and dark optical solitons, propagating in isotropic nonlinear dispersive media such as single-mode optical fibers, as well as analysis of the obtained results.

B4-2. A. Dakova, Z. Kasapeteva, D. Dakova, L. Kovachev, Nonparaxial solitons in air, Journal of Physics: Conference Series, Volume 2487, 012029, (2023), XXII International Conference and School on Quantum Electronics (ICSQE 2022), Online ISSN: 1742-6596, Print ISSN: 1742-6588, DOI 10.1088/1742-6596/2487/1/012029, **SJR$_{(2022)}$=0.183**.

Abstract

In the present work the soliton regime of propagation in air of ultra-short long-wavelength infrared laser pulses is investigated. The dispersion of atmospheric air in mid-infrared and long-wavelength infrared shows anomalous group velocity dispersion regions for wavelengths in the ranges of *3,5* to *4,2* μm and *9,3* to *13,5* μm. On the other hand, a nonparaxial waveguiding regime of propagation of femtosecond pulses with the shape of light discs (the transverse size is much bigger than the longitudinal one) is studied. The theoretical model allows reducing this *3D + 1* task to *1D + 1* problem in the same manner as in optical fibers. The combination between anomalous group velocity dispersion and atmospheric nonlinearity is a base for the observation of optical solitons in the air transparency regions for the indicated wavelengths. The main equation in our research is the *1D + 1* nonlinear nonparaxial amplitude equation, written in Galilean and Laboratory coordinate systems. New analytical solution in the form of bright soliton is found. The critical power, needed for the observation of these solitons is of two orders of magnitudes less than the critical one for self-focusing. That is why there are no conditions for ionization of the medium.

The presented results in this work are of great importance for the more successful description of the processes observed during the propagation of broad-band laser pulses in air. They can find application in the atmospheric observation systems, LIDAR systems, telecommunication systems and many others.

The candidate's personal contribution consists of the analytical calculations for finding solution of the 1D + 1 nonlinear nonparaxial amplitude equation, describing the evolution of bright optical soliton in air, as well as analysis of the obtained results.

B4-3. Aneliya Dakova, Yaldaz Murad, Zara Kasapeteva, Diana Dakova, Valeri Slavchev, Lubomir Kovachev, Anjan Biswas, Cnoidal waves and dark solitons with linear third-order dispersion and self-steepening effect, Optik, 270, 170035, (2022), ISSN 0030-4026, https://doi.org/10.1016/j.ijleo.2022.170035, **SJR(2022)=0.539, IF(2022)=3.1, (Q2)**.

Abstract

The present paper investigates the conditions needed for the generation and propagation of cnoidal waves in the form of dark solitons under the influence of self-steepening effect (SSE) and linear third-order dispersion (TOD). This kind of optical pulses could be obtained in single-mode waveguides due to the precise balance between higher orders of nonlinear and dispersive phenomena. As a basic equation, it is used the nonlinear amplitude equation (NAE). It is found a new analytical solution of this equation in the form of a cnoidal wave (Jacobi elliptic sine function). In the article it is presented that the solution can be reduced to dark soliton at specific values of the modulus of ellipticity κ.

In the current article we studied analytically the propagation of optical pulses with broad-band spectrum in single-mode waveguides. The dispersion of the fiber is normal. We have shown that under certain conditions in such media dark solitons can be observed. New exact solution of the nonparaxial NAE is obtained by taking into account TOD and SSE. The found solution presents periodic cnoidal wave (Jacobi elliptic sine function). For fixed value of the modulus of ellipticity $\kappa \to 1^-$ it is formed a dark soliton. It is important to note that the found solution is different from the standard dark soliton, described in the frames of NSE. It leads to a new kind of nonlinear dispersion ratio. It involves two additional dimensionless parameters: (α), connected with nonparaxiality and (σ), characterizing the relation between group velocity dispersion and TOD. They significantly affect the modulus of ellipticity κ.

The presented solutions are important for the better description of the evolution in optical waveguides of short laser pulses, affected by TOD and SSE. The results have application in modern communications systems for the transmission of optical signals at long distances.

The candidate's personal contribution consists of the analytical calculations for finding exact soliton solution of the nonparaxial NAE by taking into account TOD and SSE, as well as analysis of the obtained results.

B4-4. Zara Kasapeteva, Aneliya Dakova, Stefka Krasteva, Valeri Slavchev, Diana Dakova, Lubomir Kovachev, Anjan Biswas, Bright solitons under the influence of third-order dispersion and self-steepening effect, Optical and Quantum Electronics, 54, 352, (2022), Electronic ISSN 1572-817X, Print ISSN 0306-8919, https://doi.org/10.1007/s11082-022-03686-9, **SJR(2022)=0.433, IF(2022)=3.0, (Q2)**.

Abstract

In the present work the propagation of broad-band bright solitons under the influence of third-order of linear dispersion (TOD) and self-steepening effect (SSE) in single-mode fibers is analytically studied. Such optical pulses can be observed as a result of the dynamic balance between higher orders of dispersive and nonlinear phenomena. New analytical solutions of the nonlinear amplitude equation (NAE) in the form of cnoidal waves are found. The solutions are presented by Jacobi elliptic delta functions. It is shown that at certain values of the parameter κ, representing modulus of ellipticity, the solutions can be reduced to *sech*-soliton.

Obtained results are important for the better understanding of the propagation of ultra-short light pulses in nonlinear dispersive media under the influence of third order of linear dispersion and self-steepening effect. They can be used in telecommunications technology for signal transmission across long distances.

The candidate's personal contribution consists of the analytical calculations for finding new solutions of NAE in the form of cnoidal waves and bright solitons by taking into account TOD and SSE, as well as analysis of the obtained results.

B4-5. A. Dakova, D. Dakova, Z. Kasapeteva, V. Slavchev, L. Kovachev, Degenerate four-photon parametric processes, energy exchange between the components and nonlinear polarization rotation, Optik, Volume 242, 166996, (September 2021), ISSN: 0030-4026, https://doi.org/10.1016/j.ijleo.2021.166996, **SJR$_{(2021)}$=0.523, IF$_{(2021)}$=2.840, (Q2)**.

Abstract

In the present paper the influence of degenerate four-photon parametric process on the energy exchange between the components of the electrical field for different polarization states of optical pulses is studied. The natural basis for investigating this phenomenon is a system of two coupled nonlinear equations. They govern the interaction between x and y components of laser pulses. A new class analytical solutions, describing the energy exchange between the components of the electric field is presented, where the influence of the effects of self- and cross-phase modulation on the energy exchange period is taken into account. The analytical solutions are compared with the numerical calculations.

A detailed analysis of the energy exchange in the case of elliptical polarization of a laser pulse, propagating in single-mode optical fiber is done. In the case of elliptical polarization the periodical energy exchange between the components of the optical field is investigated for different initial amplitudes and phases. It turns out that the period of energy exchange depends mainly on the initial phase difference of the two components, determining the degree of ellipticity. Our investigations show that this dependence is much weaker according to the initial difference in the amplitudes of the components.

The obtained analytical results for the period of energy exchange can be used in the development and construction of various optical devices and switchers.

The candidate's personal contribution consists of the analytical calculations for finding new solutions of the system of two coupled nonlinear equations, describing the energy exchange between the components of the electric field by taking into account the influence of the effects of self- and cross-phase modulation, as well as analysis of the obtained results.

B4-6. A. Dakova, D. Dakova, Z. Andreeva, V. Slavchev, L. Kovachev, Mutual action of self-phase modulation and cross-phase modulation on the parametric four-photon mixing. Exact analytical solutions in the form of Jacobi functions, Optik, Volume 194, 163024, (October 2019), ISSN 00304026, 16181336, https://doi.org/10.1016/j.ijleo.2019.163024, **SJR$_{(2019)}$=0.475, IF$_{(2019)}$=2.187, (Q2)**.

Abstract

The purpose of this work is to investigate the influence of the self-phase modulation (SPM) and cross-phase modulation (CPM) on the parametric interaction between pump, signal and idler at few coherent lengths. The coherent length of four-photon mixing process can be quite long, from *500 m* up to *1 km*, if the spectral separation between the signal waves is relatively small. The problem with the generation of new frequencies on distances less than one coherent length in parametric four-photon processes, without including the Raman scatter was solved only in approximation for a fixed electric field or fixed intensity of the pump wave. The overall task which includes the change in intensity and the phase of the pump wave has not been studied in detail in the literature up to now. The main purpose of the present work is to solve the more general problem: the mutual action of all $\chi^{(3)}$ nonlinear processes on the parametric four-photon mixing.

In present work is investigated the process of four-photon mixing between pump, signal and idler at few coherent lengths. At these distances the group velocity dispersion (GVD) is negligible, it but has significant importance in the phase matching conditions. On the other hand, SPM and CPM are of the same order as the parametric possesses, because they are due to the real part of the cubic nonlinear susceptibility. The process is described by a system of three nonlinear differential equations. New mathematical method for solving this nonlinear parametric system is used. It can be applied for waves with arbitrary initial intensities, generalized phase and presence of wave number mismatch. As a result exact analytical solutions, which describe the periodic energy exchange between signal, idler and pump waves under the SPM and CPM influence are found. The solutions are presented in the form of Jacobi's elliptic sine functions. A connection between Jacobi's κ parameter, the initial intensities and phases of the optical waves, and wave number mismatch Δk is obtained.

The candidate's personal contribution consists of the analytical calculations for finding exact solutions of the system of equations, which describe the periodic energy exchange between *signal, idler and pump waves under the influence of SPM and CPM, as well as analysis of the obtained results.*

B4-7. A. Dakova, L. Kovachev, D. Dakova, D. Georgieva,V. Slavchev, Degenerate four-photon parametric processes and vector solitons, Optik, Volume 168, p. 721-727, (September 2018), ISSN 00304026, 16181336, https://doi.org/10.1016/j.ijleo.2018.04.133, **SJR$_{(2018)}$=0.404, IF$_{(2018)}$=1.914, (Q2)**.

Abstract

In the present work we investigate more precisely the influence of degenerate four-photon parametric process (DFPP) on the soliton propagation and the periodic exchange of energy between elliptically polarized waves. The obtained nonlinear dispersion relations describe clear physical picture of balance between dispersion and different kinds of nonlinear phase modulations of linearly and circularly polarized solitons. In quasi-CW regime, the system of equations is analytically solved. The obtained solutions, in the form of Jacobi elliptic functions, describe the evolution of the intensities' components of the vector field.

It is investigated the dynamics of three types of vector solitons – circularly, linearly and elliptically polarized. The relation between the intensities of circularly polarized and linearly polarized solitons, as well as the relation of their energy integrals is *3/2*. Our investigation shows that DFPP wave mixing terms in the main systems of equations act as usual cross-modulation terms with different sign, depending on the polarization states – linear or circular. In the case of elliptic polarization the soliton-like character of the pulse is preserved, but the components of the field periodically exchange energy. The period of oscillation strongly depends on the initial phase difference between the components. This phenomenon leads to periodicity in the rotation of the polarization's ellipse.

Elliptically polarized solitons can be used for applications in optical devices as polarization rotators. When the second order of dispersion is neglected the system of shortened equations can be analytically solved. We have found exact analytical solutions for arbitrary initial phase difference between the components of the field.

The candidate's personal contribution consists of the analytical calculations for finding exact solutions of the system of equations for arbitrary initial phase difference between the components of the field, as well as analysis of the obtained results.

- **According to criterion G7: Scientific publication in journals that are referenced and indexed in world-renowned databases with scientific information (Web of Science and Scopus), outside of the habilitation thesis:**

Г7-1. Oswaldo González-Gaxiola, Anjan Biswas, Yakup Yildirim, Anelia Dakova, Numerical Simulation of Highly Dispersive Dark Optical Solitons with Kerr Law of Nonlinear Refractive Index by Laplace–Adomian Decomposition Method, Proceedings of the Bulgarian Academy of Sciences (Comptes rendus de l'Acad´emie bulgare des Sciences), Vol. 76(5), pp. 677–688, (2023), ISSN: 1310–1331 (Print), 2367–5535 (Online), https://doi.org/10.7546/CRABS.2023.05.03, **SJR$_{(2022)}$=0.182, IF$_{(2022)}$=0.3, (Q3)**.

Abstract

This work is a numerical perspective to highly dispersive dark optical solitons by using Laplace-Adomian decomposition method. The results are reported using this scheme with highly precise accuracy and the error measure is stunningly low. The surface plots, density plots and error plots are exhibited for different parameter choices. The simulations are almost an exact replica of such solitons that analytically arise from the governing system. The suggested iterative scheme finds the solution without any discretization, linearization, or restrictive assumptions.

The candidate's personal contribution consists of the analysis and validation of the analytical calculations for highly dispersive dark optical solitons, obtained by using Laplace-Adomian decomposition method and the physical interpretation of the results.

Г7-2. O. Gonzalez-Gaxiola, Anjan Biswas, Hashim M. Alshehri, Aneliya Dakova, Numerical simulation of cubic-quartic optical soliton perturbation by the Laplace-Adomian decomposition, Proceedings of the Bulgarian Academy of Sciences (Comptes rendus de l'Acad´emie bulgare des Sciences) Vol. 76(7), pp. 1008–1019, (2023), ISSN: 1310–1331 (Print), 2367–5535 (Online), https://doi.org/10.7546/CRABS.2023.07.04, **SJR$_{(2022)}$=0.182, IF$_{(2022)}$=0.3, (Q3)**.

Abstract

The current paper is on the numerical analysis of bright and dark cubic-quartic (CQ) solitons that emerges from the Fokas–Lenells equation (FLE) with Hamiltonian perturbation terms. The Kerr law of nonlinearity is the source of self-phase modulation. The adopted numerical scheme is the Laplace–Adomian decomposition (LADM).

The presented article is the analysis from numerical perspective for CQ solitons that comes with Hamiltonian perturbations which did not destroy the integrability of the model. The LADM approach yielded bright and dark CQ solitons that emerged from the FLE. The error plots, surface plots as well as the contour plots of bright and dark CQ solitons are exhibited in the work.

The candidate's personal contribution consists of the analysis and validation of the analytical calculations for obtaining bright and dark CQ solitons that emerges from FLE with Hamiltonian perturbation terms and the physical interpretation of the results.

Г7-3. V. Slavchev, A. Dakova, D. Dakova, I. Bozhikoliev, L. Kovachev, A. Biswas, New vector type optical vortex structures in isotropic media, Journal of Physics: Conference Series, Volume 2487, 012030, (2023), XXII International Conference and School on Quantum Electronics (ICSQE 2022), Online ISSN: 1742-6596, Print ISSN: 1742-6588, DOI 10.1088/1742-6596/2487/1/012030, **SJR$_{(2022)}$=0.183**.

Abstract

In the present work, the formation of vector-type vortex structures in isotropic media is studied. These vortices exist in the electric field components and generate a depolarization in the vector field of the laser spot. Their behavior is governed by a system of amplitude equations. Additionally, new solutions have been found that describe similar types of vortex structures in an optical fiber. Thece optical vortices admit only amplitude-type singularities. The vortex structures observed within the vector amplitude function have ring-like patterns. The variation of the intensities of the *x* and *y* components of the optical pulse along the axis of the fiber is investigated.

In the current article, an approach for finding solutions of the system of nonlinear amplitude equations (NAE) characterizing the dynamics of the components of *3D* laser pulses in isotropic nonlinear dispersive materials is presented. A new class of exact analytical solutions is found in the form of optical vortex structures. These optical vortices have ring-like patterns. The behavior of this type of laser vortices was studied, depending on the value of the parameter ξ. The ring structure of the vortices significantly changes at larger values of ξ. In the vector diagram of the amplitude function a depolarization that also depends on this parameter is observed.

The nonlinear dispersion relations, following from obtained vortices, demonstrate that their stability is a result of the balance between diffraction and nonlinearity, as well as the nonlinearity and the angular field distribution.

The candidate's personal contribution consists of the analytical calculations for finding vortex solutions of the system of NAE, characterizing the dynamics of the components of 3D laser pulses in isotropic nonlinear dispersive materials, as well as analysis of the obtained results.

Г7-4. Z. Kasapeteva, A. Dakova, V. Slavchev, D. Dakova and L. Kovachev, Rotation of the polarization ellipse for broad-band and narrow-band optical pulses. Analytical solutions, Journal of Physics: Conference Series, Volume 2487, 012031, (2023), XXII International Conference and School on Quantum Electronics (ICSQE 2022), Online ISSN: 1742-6596, Print ISSN: 1742-6588, DOI 10.1088/1742-6596/2487/1/012031, **SJR$_{(2022)}$=0.183**.

Abstract

In present days the evolution of broad-band laser pulses, propagating in various types of waveguides, has been of a great interest among the scientists. Currently, it is easy for phase-modulated femtosecond pulses the condition $\Delta\omega \approx \omega_0$ to be obtained. It is known that nowadays it is possible also to reach the attosecond region, where the spectral bandwidth of the pulse happens to be of order of the carrier frequency also. Light pulses who fulfil this initial condition are called broad-band. On the other hand, the non-fulfilling pulses are the narrow-band ones. For them $\Delta\omega << \omega_0$.

In the present paper it is investigated the interaction of two components of one optical pulse by using the generalized system of nonlinear amplitude equations (GSNAE). It was analytically solved. The derived solution represents the difference in the period of oscillations of the energy exchange between the components of the optical pulse in the nonparaxial case. In this expression are included constants, which depend on the initial energy of the two components, the nonlinearity of the medium and the number of oscillations under the pulse envelope. The presented result is different from that, obtained in the frame of paraxial system of nonlinear Schrödinger equations. The effect is called rotation of the polarization ellipse.

The candidate's personal contribution consists of the analytical calculations for finding a solution of GSNAE for the interaction of two components of one optical pulse, as well as analysis of the obtained results.

Г7-5. Valeri Slavchev, Ivan Bozhikoliev, Zhelyazko Zamanchev, Aneliya Dakova, Kamen Kovachev, Anjan Biswas, Optical vortices in waveguides with spatial dependence of the nonlinear refractive index, Optical and Quantum Electronics, 54, 346, (2022), Electronic ISSN 1572-817X, Print ISSN 0306-8919, https://doi.org/10.1007/s11082-022-03707-7, **SJR$_{(2022)}$=0.433, IF$_{(2022)}$=3.0, (Q2)**.

Abstract

In the present work, the formation of optical vortex in waveguides, with spatial dependence of the nonlinear refractive index, is studied. The propagation of such type of laser pulses is governed by a system of amplitude equations for *x* and *y* components of the electrical field in which the effects of second-order dispersion and self-phase modulation are taken into account. The corresponding system of equations is solved analytically. New class of exact solutions, describing the generation of vortex structures in the optical fibers with spatial dependence of the nonlinear refractive index and anomalous dispersion, are found. These optical vortices admit only amplitude type singularities. Their stability is a result of the delicate balance between diffraction and nonlinearity, as well as nonlinearity and angular distribution. This kind of singularities can be observed as a depolarization of the vector field in the laser spot.

Ring structures in the x and y components of the electrical field are obtained. The maxima in the A_x component coincide with the minima in A_y. As a result, the ring structures in the total field of the pulse intensity are not observed, due to the compensation of the rotation in the two components. The value of the parameter m determines the number of rings observed in the intensity profiles of the components of the optical pulse. The significant growth in the number of rings leads to a narrowing of their minima and maxima. Depolarization in the diagram of the vector field is observed. Each point of the spot of the optical pulse has a different orientation of the field.

The candidate's personal contribution consists of the analytical calculations for finding vortex solutions of the system of amplitude equations for x and y components of the optical pulse, in which the effects of second-order dispersion and self-phase modulation are taken into account, as well as analysis of the obtained results.

Г7-6. Valeri Slavchev, Diana Dakova, Aneliya Dakova, Zara Kasapeteva, Lubomir Kovachev, Method for solving vector nonlinear differential equations with application in waveguide optics, AIP Conference Proceedings, 2505, 030012, (2022), ISSN 0094243X, 15517616, https://doi.org/10.1063/5.0100692, **SJR$_{(2022)}$=0.164**.

Abstract

In the present paper the vortex structures of optical pulses, propagating in gradient fiber is investigated. The optical vortices are light structures that are usually created outside the laser cavity by using different optical masks and holograms. Analytically they are described by the solutions of *2D* scalar equation of Leontovich and admit amplitude or phase dislocations.

In our work a mathematical method for solving vector nonlinear differential equations with application in waveguide optics is presented. The basic vector equation is generalized to a system of scalar equations for x and y components of the amplitude function. The system is solved analytically. New class analytical solutions, describing the generation of vector field vortices in gradient optical fibers are found. Vortex solutions for the components of the electrical field that are found have helical structures. The value of the vortex parameter n determines the number of spirals observed in the profiles of the intensity components A_x and A_y.

The candidate's personal contribution consists of the analytical calculations for finding vortex solutions with helical structures of the system of scalar equations for x and y components of the amplitude function, as well as analysis of the obtained results.

Г7-7. Aneliya Dakova, Diana Dakova, Zara Kasapeteva, Anjan Biswas, Valeri Slavchev and Lubomir Kovachev, Method for solving systems of differential equations with application in nonlinear optics, AIP Conference Proceedings, 2505, 030001, (2022), ISSN 0094243X, 15517616, https://doi.org/10.1063/5.0100693, **SJR$_{(2022)}$=0.164**.

Abstract

The present paper focuses on a specific method for solving systems of differential equations with application in nonlinear optics. The basic system is presented by two coupled nonlinear differential equations, written in dimensionless form, which govern the propagation of light pulses in optical fibers. They are partial differential equations of second order and third degree with application in nonlinear optics. The mathematical algorithm is described in detail in the article. The system is analytically solved. The obtained solutions of the equations are in the form of special functions - Jacobi elliptic delta functions. They determine the periodical energy exchange between light pulses. The mathematical method can be applied for pulses with arbitrary initial intensities, generalized phase and wave number mismatch.

The results are important not only from a fundamental but also from a practical point of view. They can be used in the development and construction of various optical devices, switchers or parametric amplifiers.

The candidate's personal contribution consists of the analytical calculations for finding solutions of the system of two coupled nonlinear differential equations, written in dimensionless form, which govern the propagation of light pulses in optical fibers, as well as analysis of the obtained results.

Г7-8. V. Slavchev, A. Dakova, N. Gocheva, I. Bozhikoliev, K. Kovachev, A. Biswas, Laser ring structures in step-index fibers, Journal of Physics: Conference Series, Vol. 2339, 012007, International Conference on Electronics, Engineering Physics and Earth Science 2022 (EEPES 2022), Online ISSN: 1742-6596, Print ISSN: 1742-6588, https://doi.org/10.1088/1742-6596/2339/1/012007, **SJR$_{(2022)}$=0.183**.

Abstract

The formation and propagation of optical ring structures, given by a system of amplitude equations for the components of the electric field is investigated. The calculations are made in approximation of second-order linear dispersion and self-phase modulation. New class analytical solutions, characterizing the generation and evolution of laser ring structures in optical waveguides with step-index profile and anomalous dispersion, are described. The stability of these optical formations is a result of the specific combination of nonlinearity, diffraction and angular distribution. Laser vortices have an amplitude type of singularity which appears as depolarization of the vector field in the light radiation spot.

In the present paper new exact solutions in the form of optical vortices for the components U_x and U_y of the vector function are obtained. Basic vector nonlinear amplitude equation is presented as a system of two differential equations in scalar form for the components of the pulse amplitude function A. The graphs for different values of the parameter V of the found solutions are shown. The results demonstrate that V governs the number of ring structures, obtained in the

intensity profiles of the pulse's components U_x and U_y. The size of the core of the vortex rings changes significantly. The points in the spot of the laser pulses have different orientations of the vector field. As a result, for the different values of the parameter V the observed depolarization in the vector field changes considerable.

The candidate's personal contribution consists of the analytical calculations for finding vortex solutions, with ring structures in the intensity profiles of the pulse's components, of the system of amplitude equations in approximation of second-order linear dispersion and self-phase modulation, as well as analysis of the obtained results.

Г7-9. Sandeep Malik, Sachin Kumar, Anjan Biswas, Mehmet Ekici, <u>Anelia Dakova</u>, Abdullah Khamis Alzahrani, Milivoj R. Belic, Optical solitons and bifurcation analysis in fiber Bragg gratings with Lie symmetry and Kudryashov's approach, Nonlinear Dynamics, Vol. 105, Issue 1, 735-751, (2021), Electronic ISSN 1573-269X, Print ISSN 0924-090X, https://doi.org/10.1007/s11071-021-06630-w, **SJR$_{(2021)}$=1.262, IF$_{(2021)}$=5.741, (Q1)**.

Abstract

A combination of Lie symmetry analysis and Kudryashov's approach secures optical soliton solutions with fiber Bragg gratings (FBGs). The bifurcation analysis is carried out and the phase portrait is presented.

In the current work, optical solitons in FBGs are studied via Lie symmetry analysis and Kudryashov's scheme for Kerr law, parabolic law, polynomial law, quadratic-cubic law, and parabolic-nonlocal combo nonlinearities. This led to the retrieval of combo bright singular solitons solutions, which can add some spectrum to the soliton solutions. With respect to polynomial law of nonlinearity, the Kudryashov's scheme failed to secure the combo bright-singular solitons solutions. Along with this, it is done phase portrait analysis with respect to Kerr law and quadratic-cubic law nonlinearity.

The candidate's personal contribution consists of the analysis and validation of the analytical calculations for optical solitons, obtained in FBGs via Lie symmetry analysis and Kudryashov's scheme and the physical interpretation of the results.

Г7-10. A. Biswas, <u>A. Dakova</u>, S. Khan, M. Ekici, L. Moraru, M. R. Belic, Cubic-quartic optical soliton perturbation with Fokas–Lenells equation by semi-inverse variation, Semiconductor Physics, Quantum Electronics and Optoelectronics, Vol. 24, No 4. p. 431-435, (2021), ISSN 1605-6582 (On-line), ISSN 1560-8034 (Print), https://doi.org/10.15407/spqeo24.03.431, **SJR$_{(2021)}$=0.16, (Q4)**.

Abstract

This paper recovers cubic-quartic (CQ) bright optical solitons with perturbed Fokas–Lenells equation (FLE). The Hamiltonian perturbation terms appear with maximal permissible intensity. The semi-inverse variational principle (SVP) is employed to retrieve such solitons.

The paper retrieved a bright single-soliton solution to the perturbed CQ-FLE, where traditional chromatic dispersion is replaced by third order dispersion and fourth order dispersion. This analytical soliton solution is not exact, since the solution is retrieved as based on SVP. This method is thus a savior in the sense that analytical soliton solutions are found when the full nonlinearity parameter is just arbitrary. This method seems to be promising for implementation of other forms of bright solitons such as cosh-Gaussian pulses and others.

The candidate's personal contribution consists of the analysis and validation of the analytical calculations for recovering CQ bright optical solitons with perturbed FLE and the physical interpretation of the results.

Г7-11. Anjan Biswas, Mehmet Ekici, Anelia Dakova, Salam Khan, Seithuti P. Moshokoa, Hashim Mohammad Alshehri, Milivoj R. Belic, Highly dispersive optical soliton perturbation with Kudryashov's sextic–power law nonlinear refractive index by semi–inverse variation, Results in Physics, Vol. 27, 104539, (August 2021), ISSN: 2211-3797, https://doi.org/10.1016/j.rinp.2021.104539, **SJR$_{(2021)}$=0.662, IF$_{(2021)}$=4.565, (Q2)**.

Abstract

A single bright highly dispersive (HD) optical soliton solution is recovered from semi-inverse variational principle (SVP). The model contains six power law nonlinear terms that constitute self-phase modulation (SPM) effect which was proposed by Kudryashov. The amplitude-width relation of the soliton was finally recovered by Cardano's approach with appropriate and necessary constraints that are presented.

This paper is about SVP applied successfully to perturbed Kudryashov's equation that contains six nonlinear forms of SPM. In this context, bright HD 1-soliton solution is revealed. This analytical solution is in its closed form although not an exact solution. A version of the variational principle, commonly referred to as SVP, has made this retrieval possible. A numerical simulation is also presented. The perturbation terms are with maximum intensity. No known integration scheme can possibly identify a closed form solution. Thus, SVP is to the rescue. One other shortcoming, however, of the scheme is that it fails to retrieve dark or singular soliton solution.

The candidate's personal contribution consists of the investigation and validation of the analytical calculations for HD solitons, recovered from SVP.

Г7-12. Yakup Yıldırım, Anjan Biswas, Anelia Dakova, Salam Khan, Seithuti P. Moshokoa, Abdullah Khamis Alzahrani, Milivoj R. Belic, Cubic–quartic optical soliton perturbation with Fokas–Lenells equation by sine–Gordon equation approach, Results in Physics, Volume 26, 104409, (July 2021), ISSN: 2211-3797, **$SJR_{(2021)}$=0.662, $IF_{(2021)}$=4.565, (Q2)**.

Abstract

This paper recovers cubic-quartic (CQ) optical solitons for perturbed Fokas–Lenells equation (FLE) in polarization-preserving fibers and birefringent fibers. The perturbation terms appear with maximum permissible intensity. Singular and dark solitons, together with a few combo solitons, emerge from the sine–Gordon equation integration scheme. This article applied sine–Gordon equation approach and recovered combo singular, singular and dark singular solitons to FLE both in polarization-preserving fibers as well as birefringent fibers. The existence restriction for such solitons has been also presented. The Hamiltonian perturbation terms are considered with maximum allowable intensity while the solitons are recovered for a specific value of this full nonlinearity parameter. Such is the shortcoming of this approach.

The candidate's personal contribution consists of the data curation and formula analysis of the analytical calculations for recovering CQ optical solitons for perturbed FLE in polarization-preserving fibers and birefringent fibers.

Г7-13. V. Slavchev, A. Dakova, I. Bojikoliev, D. Dakova, L. Kovachev, Helical vortex structures and depolarization in fiber with concave-gradient profile, Optik, Volume 242, 167124, (September 2021), ISSN: 0030-4026, https://doi.org/10.1016/j.ijleo.2021.167124, **$SJR_{(2021)}$=0.523, $IF_{(2021)}$=2.840, (Q2)**.

Abstract

In the recent years the investigation of the evolution of optical pulses in concave-gradient fiber is of a great interest. In the present paper the vortex structures of optical pulses, propagating in such fiber is investigated. Their dynamic is governed by the vector nonlinear amplitude equation. We generalize this equation to a scalar system of equations for x and y components of the amplitude function. New class vortex solutions of these equations are found. The graphs of the components of the electric field that we obtained based on the found solutions, present helical structures. The number of helixes corresponds to the vortex parameter n. Specific characteristics of these vortices is that they exist in the frames of the optical pulse's components. In the field of the total intensity, as a result of the superposition of the two components, the vortex structures disappear. To observe experimentally these vortices it is necessary one of the components to be filtered. Characteristic feature of such vortex structures is that they generate depolarization of the vector field. In each point of the spot of the pulse different orientation of the vector field is observed.

The candidate's personal contribution consists of the analytical calculations of the system of equations for finding vortex solutions with helical structures in the x and y components of the laser pulse, propagating in concave-gradient fiber, as well as analysis of the obtained results.

Г7-14. B. Nenova, D. Dakova, A. Dakova, V. Slavchev, L. Kovachev, Propagation of ultra-short dark soliton pulses in an isotropic medium under the influence of third-order linear dispersion and nonlinearity dispersion, XXI International Conference and School on Quantum Electronics, IOP Publishing, Journal of Physics: Conference Series, 1859, 012051, (2021), doi:10.1088/1742-6596/1859/1/012051, Online ISSN: 1742-6596, Print ISSN: 1742-6588, **SJR$_{(2021)}$=0.21**.

Abstract

The nonlinear Schrödinger equation (NSE) is well-known and is one of the most commonly used in the field of nonlinear optics. Pulses with picosecond and nanosecond duration are very well described by NSE, but it does not work properly for attosecond and phase-modulated femtosecond laser pulses, where the spectral width of the pulse is of the order of the carrying frequency. In such cases, it is more convenient to use the general nonlinear amplitude equation (NAE). During the propagation of ultra-short pulses in optical fibers, the effects of the third-order linear dispersion and dispersion of nonlinearity become significant and have to be taken into account. We expanded the NAE by including these two effects.

In the present paper we investigated the evolution of broad-band laser pulses propagating in single-mode fibers with normal dispersion, where dark solitons can be observed under certain conditions. A new analytical soliton solution of NAE was found with respect to the effects up to the third order of linear dispersion and dispersion of nonlinearity. The obtained solution differs significantly from the standard soliton solution of NSE. The constant *U*, connected with the velocity of the temporal shift, depends on the coefficients characterizing the second and third order of the linear dispersion and the nonlinearity of the medium, as well as the number of harmonic oscillations under the pulse's envelope. The numerical calculations demonstrated considerable temporal shift for ultra-short optical pulses.

The candidate's personal contribution consists of the analytical calculations for finding dark soliton solution of NAE, taking into account the effects up to the third order of linear dispersion and dispersion of nonlinearity, as well as analysis of the obtained results.

Г7-15. V. Slavchev, A. Dakova, I. Bojikoliev, D. Dakova, L. Kovachev, Generation of vector type vortices in gradient fiber with spatial dependence of the refractive index, Journal of Optoelectronics and Advanced Materials, Vol. 22, No. 9-10, p. 445-451, (September – October 2020), ISSN 14544164, **SJR$_{(2020)}$=0.188, IF$_{(2020)}$=0.587, (Q3)**.

Abstract

The optical vortices are usually created outside the laser cavity by using different optical masks and holograms. The vortex structures are characterized by helical phase fronts. Their solutions are governed by *2D* Leontovich scalar equation and admit amplitude or phase singularities.

In present work we investigated the formation of vector vortex structures in the components of laser pulses, propagating in concave and convex gradient optical fibers in nonlinear regime. The corresponding system of amplitude equations is solved analytically and new class exact solutions, describing the generation of vector vortices in gradient optical fibers with spatial dependence of the refractive index are found. They have no singularity in the phase. These new vector vortices admit amplitude type singularities only. Experimentally, this will manifests as depolarization of the vector field in the pulse spot. Numerical simulations of the exact analytical solutions were made in two cases, depending on the coefficient S_g, taking into account the spatial dependence of the refractive index. The nonlinear dispersion relations of these vector vortex solutions are obtained as balance between diffraction, nonlinearity and angular distribution of the field. Thus, a stability of the vortices can be expected.

The candidate's personal contribution consists of the analytical calculations for finding new solutions of the system of amplitude equations, describing the generation of amplitude-type vortices in gradient optical fibers with spatial dependence of the refractive index (concave and convex), as well as analysis of the obtained results.

Г7-16. B. Nenova, A. Dakova, D. Dakova, V. Slavchev, L. Kovachev, Dark Broad-Band Solitons And Opposite Self-Frequency Shift, AIP Conference Proceedings, (2019) Volume 2164, Article number 100006, ISSN 0094243X, 15517616, https://doi.org/10.1063/1.5130843, **SJR(2019)=0.19**.

Abstract

In the present paper the propagation of ultra-short dark solitons in nonlinear dispersive optical fibers, described in the frames of the nonparaxial nonlinear amplitude equation (NAE) is investigated. The nonparaxial equation governs the evolution of narrow-band, as well as broad-band laser pulses with few oscillations under the envelope. We are looking for a solution of that equation, describing the propagation of broad-band laser pulses in single-mode optical fibers with normal dispersion. Analytical solutions in the form of dark solitons are found.

In the article was shown a mathematical algorithm for solving NAE, which describes more correctly the real evolutionary processes of broad-band optical pulses, as well as narrow-band. The equation admits exact solution under the form of dark soliton, propagating in isotropic nonlinear dispersive single-mode optical fibers. Its stability is due to the balance between normal dispersion

and nonlinearity. The main difference between the obtained in the article solution and the soliton solution of the classical nonlinear Schrödinger equation is in their phases.

A number of numerical simulations of the dark soliton solution are performed. They show that for laser pulses with few optical cycles under their envelope, described by NAE, a significant temporal shift of the position of the soliton's gap is observed. This temporal shift is inversely proportional to the initial pulse duration. For narrow-band optical pulses (with many oscillations under the envelope), the evolution of black solitons differs from that of the broad-band black soliton. The temporal shift is weaker and it changes its direction. By performing the numerical calculations it is made clear the influence of the two additional nonparaxial terms in NAE on the parameters of the black soliton. The obtained results are important for the better understanding and description of the behavior of ultra-short laser pulses propagating in single-mode fibers and planar waveguides.

The candidate's personal contribution consists of the analytical calculations for finding dark soliton solution of the nonparaxial NAE, describing the propagation of ultra-short laser pulses in isotropic nonlinear dispersive single-mode optical fibers, as well as analysis of the obtained results.

Г7-17. I. Bozhikoliev, K. Kovachev, A. Dakova, V. Slavchev, D. Dakova, L. Kovachev, Vortex solutions of vector nonlinear amplitude equations in optics, Proceedings of SPIE - The International Society for Optical Engineering, Volume 11047, Article number 110471C, (2019), ISSN: 0277786X, ISBN: 978-151062768-0, https://doi.org/10.1117/12.2519026, **SJR$_{(2019)}$=0.215**.

Abstract

Different kind of vortex structures of laser beam can be created by optical holograms and different optical masks. In the theory these vortices are solutions of *2D* scalar Leontovich equation. These solutions admit amplitude or phase singularities.

The main tack of this work is to investigate the possibility of formation of vortex structures for narrow-band optical pulses, propagating in Kerr-type media. The evolution of such type of laser pulses is governed by nonlinear system of amplitude equations in second approximation of the linear dispersion. In the present work is developed a mathematical algorithm for solving the nonlinear system of spatio-temporal amplitude equations, describing the evolution of the components of laser pulses in isotropic nonlinear dispersive media. It is found new class of exact analytical solutions in the form of optical vortex structures. The nonlinear dispersion relations obtained by these vortex solutions show that their stability is due not only to balance between diffraction and nonlinearity, but also to the balance between nonlinearity and angular distribution of the field. A number of numerical simulations for the solutions of the system of equations are made.

The candidate's personal contribution consists of the analytical calculations for finding new class of exact solutions with vortex structures of the nonlinear system of spatio-temporal amplitude equations, describing the evolution of the components of laser pulses in isotropic nonlinear dispersive media, as well as analysis of the obtained results.

Г7-18. A. Dakova, D. Dakova, V. Slavchev, N. Likov, L. Kovachev, Vortex structures in optical fibers with spatial dependence of the refractive index, Journal of Optoelectronics and Advanced Materials, Vol. 21, Iss. 7-8, p. 492 – 498, (2019), ISSN 14544164, **$SJR_{(2019)}$=0.214, $IF_{(2019)}$=0.631, (Q3)**.

Abstract

It is well-known that vortex structures of laser beam can be created by different optical masks and holograms. These vortices are solutions of *2D* scalar Leontovich equation and admit amplitude or phase singularities. The main idea of present work is to investigate the formation of vortex structures for optical pulses, evolving in dispersive Kerr-type nonlinear medium with spatial dependence of the refractive index. The propagation of such type of laser pulses is governed by nonlinear system of amplitude equations. We found new class of analytical solutions with vortex structures for concave gradient fibers.

In the present work it is shown a mathematical algorithm for solving the nonlinear system of spatio-temporal amplitude equations, describing the propagation of the components of laser pulses in isotropic nonlinear dispersive optical fiber with spatial dependence of the refractive index. When the parameter characterizing the profile of the refractive index is greater than zero ($S_g > 0$), the fiber has a concave gradient profile. A new class of exact analytical solutions in the form of optical vortex structures are found. The nonlinear dispersion ratios obtained by these vortex solutions shows that their stability is due to the balance between diffraction and nonlinearity, as well as the balance between nonlinearity and angular distribution of the field. A number of numerical simulations of the solutions of the system of equations are made.

The candidate's personal contribution consists of the analytical calculations for finding new class of exact solutions, in the form of optical vortex structures, of the nonlinear system of spatio-temporal amplitude equations, describing the propagation of the components of laser pulses in isotropic nonlinear dispersive optical fiber with spatial dependence of the refractive index (concave gradient fibers), as well as analysis of the obtained results.

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