Temporal dissipative solitons in active and passive waveguides:

Model, Dynamics and Perturbative analysis

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Abstract

Temporal dissipative solitons (DSs) are stable self-localized pulse-like structures of light forming inside a nonlinear dissipative system as a result of double balance between the medium's nonlinearity and it's dispersion and between the gain and loss mechanisms. For such solitary waves, the shape, amplitude, temporal width and all other parameters are unique for a given external condition. Based on the gain feedback mechanism, the big family of temporal DSs are categorised into two subclasses: DS inside active waveguide governed by the complex cubic Ginzburg-Landau equation (GLE); and cavity soliton (CS) in an externally driven passive ring resonator governed by the Lugiato-Lefever equation (LLE). In this thesis we take a step toward unravelling the fundamental aspects of the ultrafast nonlinear dynamics of DSs and CSs in dissipative waveguides considering higher-order effects as perturbation. First, we investigate the dynamics of DSs inside an active Si-based waveguide perturbed by physical processes such as third-order dispersion (TOD), intrapulse Raman Scattering (IRS), self-steepening, and free-carrier generation by solving GLE numerically. We apply variational technique to theoretically study the physical insight of the complex mechanism of perturbed DS dynamics. We then investigate the linear radiation generated by the DS under the influence of TOD and predict the spectral location of this radiation by a modified phase matching relation which includes the effect of free-carrier dispersion. Considering the plane wave solution of the linear dispersive wave we calculate the energy of the radiation. Backed by the knowledge obtained from this elaborate study of DSs under perturbations, we step forward to explore the dynamics of DSs in a silver-nanoparticle-doped active waveguide that exhibits a strong frequency-dependent Kerr nonlinearity. For this specific system one can obtain a zero-nonlinearity frequency (ZNF) and we focus our investigation to unveil the peculiar dynamics of the DS near the ZNF. Theoretically, it is revealed that depending on the relative location of the ZNF, Raman induced frequency redshifting can be either suppressed or enhanced, and the spectral location of the phase-matched radiation generated due to TOD is also modified. Hereafter we extend our study to the dynamics of DSs in gold based active plasmonic waveguides where thermo-modulational nonlinearity of gold plays an important role. As a result of which the propagation of this DS in such a plasmonic waveguide is heavily influenced by heating and a soliton self-frequency redshift accompanied by soliton deceleration in the time domain is observed. Finally, we study the dynamics and stability of CSs inside a Si-based microring resonator in presence of perturbations like two-photon absorption, free-carrier generation, and IRS. Exploiting bistability analysis we theoretically estimate the modified stability parameters for which CS can exist under perturbation. We thoroughly investigate the effect of individual perturbations on different parameters of the CS like amplitude, width, temporal and spectral positions during propagation and theoretically establish the closed form expressions. All the theoretical results are verified by solving the LLE numerically.

Key words: Dissipative Soliton; Ginzburg–Landau Equation; Cavity Soliton; Lugiato–Lefever Equation; Third-Order Dispersion; Dispersive Wave; Intrapulse Raman Scattering; Frequency Dependent Kerr Nonlinearity; Thermo-Modulational Nonlinearity.