

Dynamics of colliding Bragg solitons in a dual-core system with separated grating and cubic-quintic nonlinearity

Nadia Anam and Javid Atai

School of Electrical and Information Engineering, The University of Sydney, NSW 2006, Australia

Abstract—We investigate the collisions of counterpropagating Bragg solitons in a dual-core optical coupler where one core has cubic-quintic nonlinearity and is coupled to another linear core equipped with a uniform Bragg grating. The outcomes of the collisions are diverse and exhibit rich dynamics.

Index Terms—Moving Bragg solitons; Bragg grating; Cubic-quintic nonlinearity

I. INTRODUCTION

The periodic variation of the refractive index along an optical fiber gives rise to fiber Bragg gratings (FBGs). In the linear regime, FBGs have been used as dispersion compensators, filters and format converters [1–3]. A well-known feature of the FBGs is that the coupling between the forward and reflected waves gives rise to a strong dispersion that can be significantly larger than the inherent dispersion of silica [4]. At sufficiently high optical intensities, the nonlinearity can counterbalance the grating-induced dispersion leading to formation of Bragg grating (BG) or gap solitons. Bragg solitons have been observed experimentally in a single Bragg grating [5, 6]. Owing to their potential applications in novel all-optical devices such as logic gates, optical delay lines and buffers, BG solitons have been investigated theoretically in different structures and nonlinearities, such as coupled Bragg gratings, photonic crystals, nonuniform gratings and cubic-quintic nonlinearity [7–10].

In this work, we analyze the dynamics of collisions of counterpropagating Bragg solitons in a semilinear coupler where one core has cubic-quintic nonlinearity while the other core is linear and is equipped with a uniform Bragg gratings.

II. THE MODEL

Starting from Maxwell’s equations and following the methods described in [7], one can derive a system of partial differential equations for the propagation of light in the dual-core system composed of a nonlinear core with cubic-quintic nonlinearity which is coupled to a linear core with a uniform Bragg grating. Upon transformation of the system to the

moving coordinates, one arrives at the following system of partial differential equations:

$$\begin{aligned}
 iU_T + i(1 - \sigma)U_X + \left[|V|^2 + \frac{1}{2}|U|^2\right]U - \\
 q \left[\frac{1}{4}|U|^4 + \frac{3}{2}|U|^2|V|^2 + \frac{3}{4}|V|^4 \right]U + \Phi = 0, \\
 iV_T - i(1 + \sigma)V_X + \left[|U|^2 + \frac{1}{2}|V|^2\right]V - \\
 q \left[\frac{1}{4}|V|^4 + \frac{3}{2}|V|^2|U|^2 + \frac{3}{4}|U|^4 \right]V + \Psi = 0, \\
 i\Phi_T + i(c - \sigma)\Phi_X + U + \lambda\Psi = 0, \\
 i\Psi_T - i(c + \sigma)\Psi_X + V + \lambda\Phi = 0.
 \end{aligned} \tag{1}$$

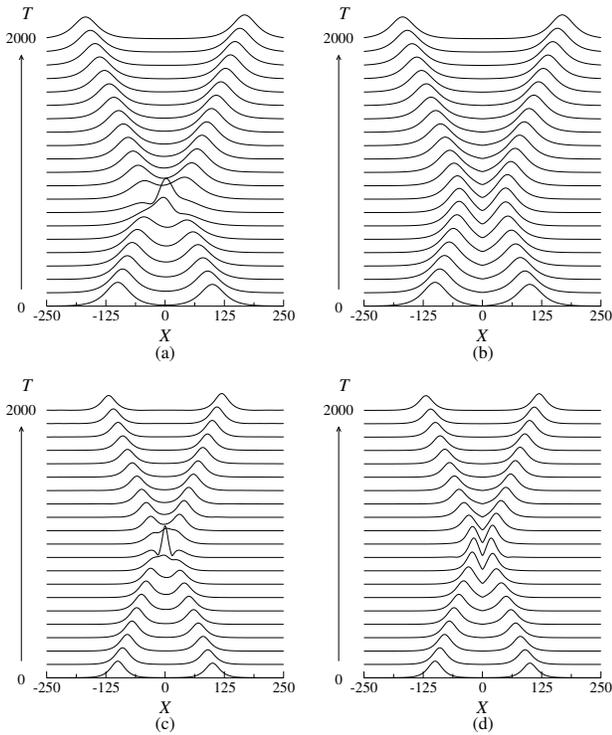
In Eqs. (1), U and V represent the forward- and backward-propagating waves in the nonlinear core, while their counterparts in the linear core are denoted by Φ and Ψ , respectively. In the nonlinear core, q denotes the strength of the fifth-order nonlinearity, and c and λ are the group velocity ratio and the BG coupling coefficient, respectively, in the linear core. The group velocity in nonlinear core has been set to 1. σ represents the normalized velocity of moving solitons.

The analysis of the linear spectrum of the system reveals that there are three band gaps in the model, termed upper, lower, and central band gaps. Moving soliton solutions only exist only in the upper and lower band gaps. There exist two types of such solitons in each bandgap, with varied parity and phase, referred to as Type 1, and Type 2.

III. COLLISION DYNAMICS

To analyze the dynamics, we numerically solve Eqs. (1) with the following initial conditions:

$$\begin{aligned}
 U(X, 0) &= U_{\sigma_+} \left(X + \frac{\Delta X}{2}, 0 \right) + U_{\sigma_-} \left(X - \frac{\Delta X}{2}, 0 \right) e^{i\Delta\theta}, \\
 V(X, 0) &= V_{\sigma_+} \left(X + \frac{\Delta X}{2}, 0 \right) + V_{\sigma_-} \left(X - \frac{\Delta X}{2}, 0 \right) e^{i\Delta\theta}, \\
 \Phi(X, 0) &= \Phi_{\sigma_+} \left(X + \frac{\Delta X}{2}, 0 \right) + \Phi_{\sigma_-} \left(X - \frac{\Delta X}{2}, 0 \right) e^{i\Delta\theta}, \\
 \Psi(X, 0) &= \Psi_{\sigma_+} \left(X + \frac{\Delta X}{2}, 0 \right) + \Psi_{\sigma_-} \left(X - \frac{\Delta X}{2}, 0 \right) e^{i\Delta\theta}.
 \end{aligned} \tag{2}$$



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Fig. 1. Examples of the collision of Type 1 stable solitons in the upper band gap at $\Omega = 1.15$, $q = 0.23$, $\lambda = 0.3$, $c = 1.5$, $\sigma = 0.1$ for (a) in-phase solitons and (b) π -out-of-phase solitons. Examples of the collision of Type 1 stable solitons in the lower band gap at $\Omega = -0.87$, $q = 0.16$, $\lambda = 0.3$, $c = 0.3$, $\sigma = 0.1$ for (c) in-phase solitons and (d) π -out-of-phase solitons.

where the subscripts σ_{\pm} denote identical velocities of the counterpropagating solitons. The initial separation and phase difference between the moving solitons are represented by ΔX and $\Delta\theta$, respectively. Moving solitons of only the Type 1 category are found to be stable; hence, our analysis has been confined to collisions of Type 1 stable solitons. Figure 1 presents examples of in-phase and π -out-of-phase collisions, respectively, in the upper and lower band gaps.

In-phase solitons in the upper and lower bandgaps, such as those in Figs. 1 (a) and (c), momentarily merge and then pass through each other with negligible decrease in energy but increase in velocity; the separation is symmetric. For the π -out-of-phase condition, two symmetrically separating solitons are generated (Figs. 1(b) and (d)). Unlike the in-phase solitons, a phase difference of π causes the velocity to decrease post collision. It is found that in majority of cases, the collisions of the moving solitons are ‘quasi-elastic’.

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