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Integrable Cross-Polarization Interactions in Optical Fibers

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1 Introduction

First predicted by Zakharov and Mikhailov in 1987 [1], optical polarization domain walls were experimentally observed about ten years later by Pitois, Millot and Wabnitz using nanosecond laser pulses, counter-propagating in nonlinear isotropic optical fibers [2, 3]. An optical polarization domain is a stable mutual arrangement of the polarization state of two light waves, in close analogy with magnetic domains in ferromagnetic materials [1]. On the other hand, an optical polarization domain wall is a kink soliton which represents a polarization switching between different domains composed of mutually orthogonal polarization states [1, 2, 3]. With perfectly isotropic fibers, in order to avoid any bending-induced birefringence, the experiments have been so far limited by the short interaction length, which is typically of the order of one meter. Such short nonlinear interaction length prevents the observation of polarization domain walls with continuous wave (CW) beams and requires using intense short optical pulses, which again limits the interaction length in a counter-propagating geometry.

We have recently extended the theory of polarization domain wall solitons to the case of both counter and co-propagating beams of different frequency in highly birefringent (hibi), twisted and spun optical fibers [4]. In the counter-propagating case, we obtained analytical domain wall soliton solutions whose propagation velocity may be controlled, and even stopped, by simply varying the input relative intensity of the two beams [5]. In this situation, for a special ratio between the linear birefringence of the fiber and the spin rate, one obtains that nonlinear cross-polarization evolutions are described by the integrable anisotropic chiral field equations. Thanks to the intrinsic polarization stability of highly birefringent fibers, the interaction lengths may be extended up to several km, which permits CW operation, and may open the way to a new class of low-power, nonlinear optical data storage and buffer devices based on the dynamic control of polarization encoded information in fiber loop memories.

For co-propagating waves with different frequencies, mutual or cross-polarization modulation interactions may have a significant impact on polarization multiplexed and wavelength-division-multiplexed (WDM) transmissions [6] and polarization-mode dispersion compensators in optical fiber communication systems [7]. We point out that in long, randomly birefringent fibers, the cross-polarization interaction leads to the integrable principal chiral field equations. Our analysis unveils the stable mutual polarization arrangements of WDM channels, reveals the existence of cross-polarization modulation supported domain wall solitons [8], and suggests novel polarization modulation schemes [9]. An interesting application of our theory is the lossless polarization attraction [10, 11] of an initially depolarized probe beam into the same polarization state of either a co-propagating or a counter-propagating pump wave. We numerically investigated the feasibility of these polarization attractors or lossless polarizers using sub-W level pumps and signals and km-long hibi fibers.

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