Non-linear polarization and chiral effects in birefringent solitons

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Abstract. Novel effects resulting from joint action of chirality and non-linearity are discussed using a basic equation describing the temporal evolution of fields in a chiral medium with Kerr non-linearity. The spatial chirality effect is characterized through the Born–Fedorov formalism. Our simulations are based on the split-step Fourier method and the solution of the Stokes parameters. The numerical results show the chiral effect on solitons with circular polarization and mixed polarization spatial solitons.

Keywords. Birefringent solitons; non-linear polarization; Schrödinger equation.

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1. Introduction

Non-linear effects resulting from polarization behavior have been of great interest because they lead to various applications, including pulse shaping, optical switching, intensity discriminators and all-optical logic gates. In optical telecommunication devices, non-linear polarization-dependent effects are also of keen interest. Also, several non-linear phenomena including optically induced birefringence, polarization instability and soliton have led to important advances from the fundamental as well as technological point of view. In addition, interest in non-linear polarization optics is expected to develop further in view of the current emphasis on photonics-based technologies for information management. Thus, a good understanding of polarization and its effects are fundamental to the design and characterization of various devices that use single-mode optical fibers. In connection with soliton pulses, Hasegawa and Tappert [1] showed that under slowly varying amplitude, electromagnetic (EM) pulse, propagating in a non-linear Kerr fiber medium, is governed by the completely integrable non-linear Schrödinger (NLS) equation

\[ i \Psi_t + \Psi_{tt} + C|\Psi|^2 \Psi = 0 \]

that admits N-soliton solutions \((C = \text{constant})\). This was derived from Maxwell equations under the assumption of weak linear dispersion.
and $\Psi$ is the slowly varying amplitude of the electric field of the electromagnetic wave. Later this was experimentally verified by Mollenauer et al.\cite{2}.

The propagation of optical pulses in birefringent fibers has become very useful in the context of non-linear directional couplers, where the dynamical equations governing the propagation of signals in the form of optical solitons, reduce to the two coupled non-linear Schrödinger family of equations

$$i\Psi_{jz} + \Psi_{jtt} + C_j |\sum_{k=1}^2 |\Psi_k|^2 \Psi_j|^2 = 0,$$

where $j = 1, 2$. Very recently, the study of propagation in birefringent optical fibers allows for introducing the new concept of shape changing solitons that share energy amongst themselves during propagation. This energy switching behavior of optical solitons can be used for constructing all optical logic gates.

When two or more optical waves co-propagate inside a birefringent single-mode fiber they differ not only in their wavelengths but also in their states of polarization. The optical pulses can further couple with each other through fiber non-linearity and the polarization of each field can change during propagation as a result of optically induced non-linear birefringence. The coupling of two waves with the same frequency but different polarizations gives rise to a number of interesting non-linear effects in optical fibers. One such effect is the polarization instability. This instability manifests itself as large changes in the output state of polarization, when the input power or the polarization state is changed slightly \cite{3}. Since then, self-induced polarization effects have been studied extensively, particularly in the context of optical Kerr effect or non-linear refractive index and remains a topic of much interest, given its practical and important consequences for laser propagation characteristics as well as its use as the basis for a wide variety of applications \cite{4}. These non-linear polarization effects in a birefringent single-mode optical fiber have led to practical applications through intensity discriminators, fiber-optic logic gates and Kerr shutters. Also, a new class of devices, among which a linear coherent amplifier mixer and an optically activated polarization switch, have been envisaged due to the intensity-dependent changes in the light polarization, as it evolves along a lossless birefringent single-mode optical fiber \cite{5,6}. The problem of the interaction between a non-linear and a DC-induced birefringence has been analytically solved by Sala for an isotropic medium \cite{7}. The form of the refractive index change, induced by the elliptically polarized pump beam, corresponds to elliptical birefringence with the important consequence that an arbitrarily polarized probe beam, in addition to reorientation, experiences a change in the shape and handedness of its polarization ellipse. Winful \cite{8} presented exact solutions for the intensity-dependent polarization state of a light wave in a birefringent optical fiber taking into account both the intrinsic linear polarization evolution and the non-linear ellipse rotation and showed that self-induced polarization changes can occur with equal excitation of the fiber principal axes. Polarization modulation instability in a birefringent optical file with fourth-order dispersion was studied by Ganapathy and Kurilaos \cite{9}. Trapped pulse generation by femtosecond soliton pulse in birefringent optical fibers has received recent attention by Nishizawa and Goto \cite{10} and the dynamics of chirped solitons in an elliptically low birefringent optical fiber is analysed by Mahmood and Qadri \cite{11}. The influence of polarization-dependent loss on birefringent fiber has been studied by Gisin et al \cite{12} and Barad and Silberberg \cite{13}. The shape-changing collision of coupled bright soliton is reviewed by Lalshmanan et al \cite{14}. While these effects on optical properties and propagation