Raman - Induced Polarization Stabilization of Vector Solitons in Circularly Birefringent Fibers

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Abstract: Perturbation analysis and numerical calculation show that Raman cross–polarization term causes the energy transferring from slower to faster circular components of vectorial solitons. This effect leads to polarization stabilization of circularly polarized vector solitons.

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1. Introduction

Common optical fibers are randomly birefringent, and solitons in them develop random polarization states upon propagation. It is desirable to have solitons with a well-defined polarization. We demonstrate here that in a circularly birefringent (twisted) fiber cross–polarization Raman term leads to one-directional energy transfer from the slow circularly polarized component to the fast one. The effect magnitude is determined by a product of birefringence and amplitudes of both polarization components. Thus, solitons with any initial polarization state will eventually evolve in a twisted fiber into stable circularly polarized ones. We demonstrate this effect numerically and make an analytic estimation of its magnitude using a perturbation theory for vector solitons [1].

2. Perturbation analysis

The propagation in a circulary birefringent fiber is governed by two coupled equations for right and left-polarized components $C^+(z,t), C^-(z,t)$:

$$i\partial_z C^+ + i\beta_1\partial_t C^+ - \frac{\beta_2}{2}\partial_t^2 C^+ = -\frac{2}{3}\gamma\left(\left|C^+\right|^2 + 2\left|C^-\right|^2\right)C^+ + \gamma T_R\left[\frac{1+\alpha}{2}\partial_t\left(\left|C^+\right|^2 + \left|C^-\right|^2\right)C^+ + (1-\alpha)\partial_t\left(Re\left(C^+C^{-*}\right)\right)C^-\right], \quad (1)$$

$$i\partial_z C^- - i\beta_1\partial_t C^- - \frac{\beta_2}{2}\partial_t^2 C^- = -\frac{2}{3}\gamma\left(\left|C^-\right|^2 + \mu\left|C^+\right|^2\right)C^- + \gamma T_R\left[\frac{1+\alpha}{2}\partial_t\left(\left|C^+\right|^2 + \left|C^-\right|^2\right)C^- + (1-\alpha)\partial_t(\mathrm{Re}(C^+C^{-*}))C^+\right]. \quad (2)$$

Here β_1 describes circular birefringence, β_2 is the second order dispersion, which is negative for soliton formation regime, γ is a nonlinear coefficient and T_R is a characteristic Raman time. The first term to the right-hand side describes the vectorial Kerr nonlinearity, and the second one the contribution of Raman effect, were a is the ratio between and perpendicular and parallel Raman amplification coefficients. It was shown that for small Raman frequency shift it approaches to 0.3 [2].

We perform the transformation of the Eqs. (1) and (2), which reduces them to a form of perturbed Manakov task [1]. The difference of Eqs. (1) and (2) with integrable Manakov case is considered as a perturbation. We obtain, that if the vector soliton can be approximated along propagation with a form

$$\left|C^+\right| \sim A\cos(\theta)\sec h[A|\beta_2|^{-1/2}(t-t_0)], \quad (3)$$

$$\left|C^-\right| \sim A\sin(\theta)\sec h[A|\beta_2|^{-1/2}(t-t_0)], \quad (4)$$

the evolution of θ is approximated by:

$$\frac{d\theta(z)}{dz} = \left(1-\alpha\right)\frac{2}{3}\gamma A^2 \frac{T_R\beta_1}{|\beta_2|}\sin(\theta)\cos(\theta) \qquad (5)$$
.

It is seen, that depending on the sign of β_1 the Raman term transfers energy to one or another polarization component. The initial pulse with a correct polarization is stable: the perturbation with another circular polarization exponentially diminishes. If the initial polarization is not correct, the initial perturbation with another polarization exponentially grows. Thus, in a fiber with random birefringence one can expect random output soliton polarization after long enough propagation. But for a circularly birefringent fiber, the correct input circular polarization is stabilized by a cross-Raman term.

3. Numerical calculations

Numerical calculations confirmed the approximation. We solved the Eqs. (1) and (2) using a split-step method. We use the fiber with nonlinearity of 1.6 1/W-km, $\beta_2 = 25ps^2/km$, and $\beta_1 = 1ps/km$. The used parameters correspond to a standard fiber twisted by approximately 6 turns per meter. First we introduced to the fiber 40 W, 30 ps pulse with elliptical polarization. The pulse broke-up to solitons. We withdraw the highest one, launched it again to the fiber and calculated the ratio between power of the circularly-right and left components that gives the angle θ. The result is presented on the Fig. 1. We have found a good agreement between analytical approximation and numerical calculations for angles higher than 0.15π. For lower angles, corresponding to unstable polarization the agreement was no so good. Numerical calculation has shown that the fast circular component is stable.

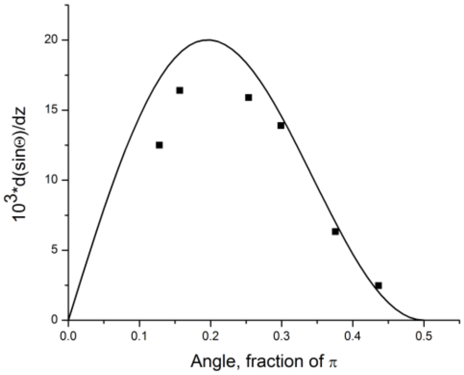

Fig. 1. Dependence of d(*sin(θ)*)/dz on the angle *θ.* Solid line – from Eq. (5); squared – from the numerical calculation

4. Aknowledgment

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5. References

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