Simulation of gain saturation on dark soliton switching in Er^{+3}- doped chalcogenide glasses

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Abstract- **We have investigated numerically the gain saturation effect on the dark soliton switching in Er^{+3}-doped chalcogenide glasses nonlinear directional couplers (NLDC). The results show the dark soliton switching is more stable than bright in the presence of gain saturation. Also the length of switch is optimized based on the numerical simulation of pulse propagation in the NLDC.**

I. INTRODUCTION

The fiber amplifiers are produced by doping the fiber with rare-earth ions such as erbium [1-3]. In this paper we have used this element for doping chalcogenide glasses [4] to study the switching behavior. The high nonlinear refractive index of chalcogenide glasses and their positive dispersion [4] make them good candidates for dark soliton switching. In this investigation, we have used the complex Ginsburg-Landau equation to extended gained nonlinear directional couplers equation. Equations are solved numerically for dark solitons in Er^{+3}-dope chalcogenide glasses. We have used a combination of Runge-Kutta and Crank-Nicolson method to simulate the pulse propagation in NLCD. The program is written in matlab software programing.

II. EQUATIONS

NLDCs are made of two single mode optical waveguides or fibers which are adjacent to each other. To investigate the gain saturation effect on NLDC, we extend the NLDC equation based on the derivation of the nonlinear Schrödinger equation [4, 11]. By using the dimensionless pulse envelope u and v [11] corresponding to upper and lower fiber of NLDC respectively, the coupled nonlinear equation of pulses in gain saturated NLDC media can be written as:

$$\begin{aligned}\frac{\partial u}{\partial \xi} &= \frac{1}{2}\left[d\exp\left[-s\int_{-\infty}^{t}|u|^2 d\tau\right] - i\,\mathrm{sgn}(\beta_2)\right]\frac{\partial^2 u}{\partial \tau^2} \\ &\quad + \frac{1}{2}\mu\exp\left[-s\int_{-\infty}^{\tau}|u|^2 d\tau\right]u + iN^2|u|^2 u + i\chi v \end{aligned} \tag{1}$$

$$\begin{aligned}\frac{\partial v}{\partial \xi} &= \frac{1}{2}\left[d\exp\left[-s\int_{-\infty}^{t}|u|^2 d\tau\right] - i\,\mathrm{sgn}(\beta_2)\right]\frac{\partial^2 u}{\partial \tau^2} \\ &\quad + \frac{1}{2}\mu\exp\left[-s\int_{-\infty}^{\tau}|u|^2 d\tau\right]u + iN^2|u|^2 u + i\chi u \end{aligned} \tag{2}$$

Where ξ is normalized propagation length, τ is normalized time, $s=p_0T_0/E_S$ is the gain saturation constant and produced gain dispersion by erbium ions, T_0 is initial pulse width, E_s is saturation energy, d is the net linear gain, μ and N are defined as $d = g_0 T_2^2 / n_0|\beta_2|$, $\mu = [g_0/n_0 - \alpha_f]L_D$, $N^2 = L_D / L_{NL}$. T_2 is the dipole relaxation time which is about (50-100fs), χ is coupling coefficient, L_D dispersion length, L_{NL} is nonlinear length, g_0 is linear gain, n_0 is refractive index and α_f is linear absorption coefficient. These equations are reduced to the generalized nonlinear Schrödinger equation for amplifiers by taking $\chi=0$, $d = 0$ and $\mu = 0$ [11].

III. EFFECT OF THE GAIN SATURATION ON DARK SOLITON NLDC

The propagation of dark solitons in Er^{+3}-doped, $Ga_5Ge_{20}Sb_{10}S_{65}$ chalcogenide glasses NLCD is simulated. The input pulses for two fibers in the dark solitons are $u(\xi = 0, \tau) = \sqrt{p_0}\tanh(\sqrt{p_0}\tau)$ and $v(\xi = 0, \tau) = 0$. The other parameters are $n_2=0.7\times10^{-18}$, g=7dB and $A_{eff}=50\mu m^2$[7].

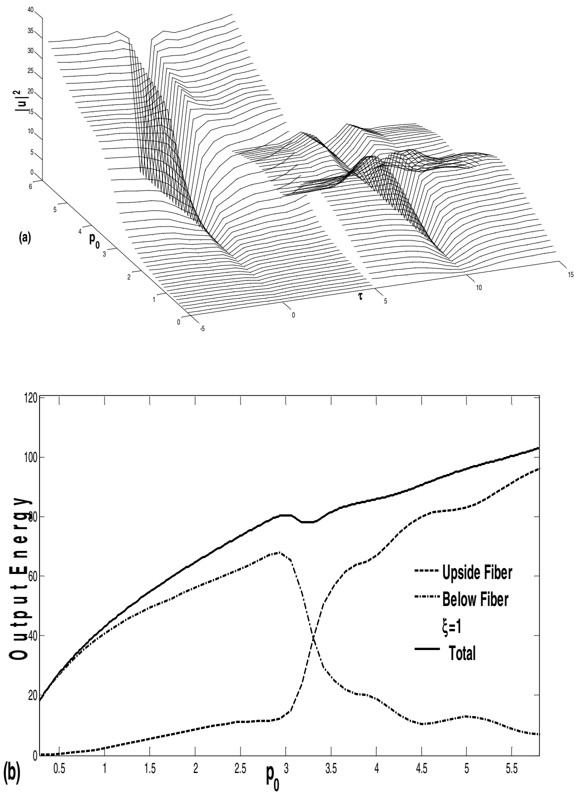

Fig. 4. (a) The dimensionless power of output pulse (b) energy of output pulse with respect to the input power by taking coupling coefficient $\chi = \pi/2$, length $\zeta=1$ for a dark soliton in normal region.

The results for output energy with respect to various input pulse powers is brought in table I. The figure 1-a shows the shape of the output pulse in upper and lower NLCD's fibers respect to the various input peak powers and in figure 1-b output energy of pulses in the two fibers and their sums are plotted.

TABLE I

THE RESULTS OF SIMULATION FOR LENGTH REDUCTION'S EFFECT ON DARK SOLITON SWITCHING.

ξ	Power of Switching at low powers	η_{low}	Power of Switching at high powers	η_{high}
1	2.94	18%	3.78	32%
0.8	2.46	22%	4.26	12%
0.7	2.22	37%	4.38	11%
0.77	2.34	25%	4.35	11%

At low powers regime, switching power decreases with reduction of length, but at high powers regime the switching power increases. Instead η_{low} is increasing but η_{high} is decreasing while ξ is decreased as can be seen from table I .

IV. SUMMARY AND CONCLUSION

We extended the NLDC equation by considering the gain saturation effect. The equations are simulated numerically by using a combination of Runge-Kutta (RK4) and Crank-Nicolson method. The Er+3-doped silicon and chalcogenide glasses nonlinear directional couplers (NLDC) are used for dark solitons switching respectively. The results show the dark soliton switching is more stable than bright in the presence of gain saturation. Also the length of switch is optimized.

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