Optical solitons switching in asymmetric dual-core nonlinear fiber couplers

X. HE[a,b], K. XIE[a*], A. XIANG[b]
[a] School of Optoelectronic Information, University of Electronics Science & Technology of China, Chengdu, 610054,China
[b] Department of Optoelectronic technology, Chengdu University of Information Technology of China, Chengdu 610225, China

The study on the switching characteristics in a asymmetric dual-core nonlinear fiber coupler has shown that the switch efficiencies when the dispersion values of two fibers have opposite signs are much higher than those when they have same signs. When the dispersion values of two fibers have same signs, the switch efficiencies become much higher if the dispersion value of one core is decreased. In addition, the switch threshold power becomes lower than the one with the same sign if the nonlinearity coefficient of two fibers is opposite. The result shows that asymmetric coupler has much higher switch efficiencies and lower switch threshold power than symmetric coupler.

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1. Introduction

All optical switching devices are attracting considerable interest as fast switching components for future high-bit-rate systems. Optical fiber couplers have been studied for their potential applications to ultra fast all optical switching processing, such as optical switch.[1~4] In a nonlinear coupler constructed from a Kerr type medium the dependence of the nonlinear refractive index n on the laser intensity is given by the expression $n=n_0+n_2I$, where n_0 is the refractive index at low intensity and n_2 is the Kerr nonlinear coefficient.[2] Jensen showed that varying the input light in the nonlinear coupler could lead to pulse switching between the two cores. He therefore foresaw the possible use of a nonlinear directional coupler as an optical switch. Previous studies of soliton switching in dual core optical fibers have shown excellent switching characteristics, with efficiencies around 96% for a wide range of input energies.[5] By comparing the switching behavior of fundamental, second order, and quasi-solitons it was observed that the fundamental soliton has the most suitable features for optical switching.[5] Indeed, it has been shown that pulse breakup may be avoided when the input signal is a soliton.[6~8] Since then, soliton switching in nonlinear fiber couplers has been receiving considerable attention.

In this paper, we will present a theoretical analysis of the switching of solitons in a dual-core nonlinear directional coupler. In the dual-core, their nonlinearity and dispersion are different respectively. This shows, by computer simulation, that if nonlinearity and dispersion of the dual-core are not the same, the excellent switching characteristics and low switching threshold power are obtained.

2. Theory

The optical solitons propagating in the NLAC can be described by a pair of coupled Nonlinear Schrödinger Equations in normalized parameters

$$i\frac{\partial u_1}{\partial \xi}+\frac{1}{2}\frac{\partial^2 u_1}{\partial \tau^2}+|u_1|^2\,u_1+ku_2=0$$

$$i\frac{\partial u_2}{\partial \xi}+\frac{1}{2}s(\xi)\frac{\partial^2 u_1}{\partial \tau^2}+g(\xi)|u|^2\,u+ku_1=0$$

where u_1 and u_2 are modal field amplitudes in soliton units with core 1 and 2. Here ξ and τ are the normalized length and time in soliton units with $\xi=z/L_D$ and $\tau=t/T_0$. Here $L_D=T_0^2/|\beta_{21}|$, where β_{21} is the group velocity dispersion of core 1. L_D and T_0 is the dispersion length and the input pulse width, respectively. $s=\beta_{22}/\beta_{21}$, $g=\gamma_2/\gamma_1$, where $\beta_{22},\gamma_1,\gamma_2$ is the group velocity dispersion of core 1, the nonlinearity coefficient of core 1 and core 2 respectively. k is the normalized coupling coefficient and is related to the normalized coupling length L_C by $k=\pi/2L_C$

3. Numerical results

In this section, we will present a numerical analysis of the switching performance of the NLAC.

We have analyzed numerically the transmission of solitons through the dual core nonlinear asymmetric coupler given by eqs.(1) and (2). The initial pulse at input core is given by:

$$u_1(0,\tau) = \sqrt{p}\,\mathrm{sec}\,h(A\tau)$$

$$u_2(0,\tau) = 0$$

Here p and A represent the solitons power, width inversion respectively. We can define the transmission T_i as a function of the pulse energies:

$$T_i = \frac{\int_{-\infty}^{+\infty} |u_i(\xi_L,\tau)|^2 \, d\tau}{\int_{-\infty}^{+\infty} |u_1(\xi_L,\tau)|^2 \, d\tau}$$

With i=1, 2 and a fiber coupler with length of ξ_L.
This system of linearly coupled NLSE(eqs.(1), (2)) was solved numerically using the split-step method with taking in account the initial conditions given by eqs.(3) and (4). Here A=1, k=1, the result is given in the figure 1~figure 4. In fig.1, it is given that g=1 and s has different value, so it means the two fibers have same nonlinearity coefficient but their dispersion values are different (except s=1).

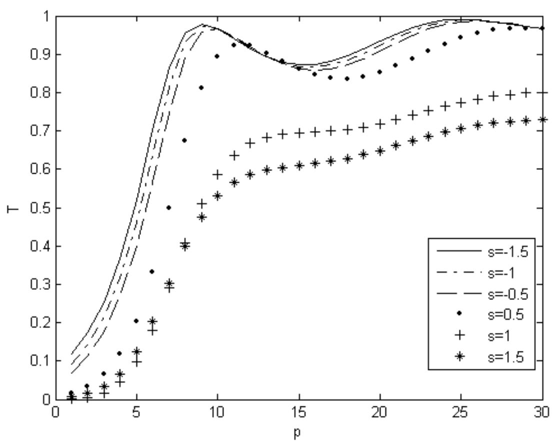

Fig.1 the transmission T of the pulse u_2 for g=1, s=-1.5,-1,-0.5,0.5,1,1.5

From fig.1, it is inferred that the switch efficiencies when s<0 are much higher than those when s>0, and those when 1>s>0 are much higher than whose when s≥1. Meanwhile, the switch efficiencies with opposite signs of dispersion values are much higher than those with same signs. When the two fibers have dispersion values with same signs, core 2 has less dispersion values and much higher switch efficiencies than core 1. Furthermore, when s<0, bigger |s| is, lower the switch threshold power are, although the switch efficiencies remains constant nearly.

In fig.2, it is given that g=-1 and the other condition is as same as fig.2. It is inferred that when the nonlinearity sign of the two fibers are the contrary, for the contrary dispersion sign of two fibers the switch efficiencies remains essentially constant and the switch threshold power become lower, and for the same dispersion sign of two fibers the switch efficiencies become higher and the switch threshold power become lower.

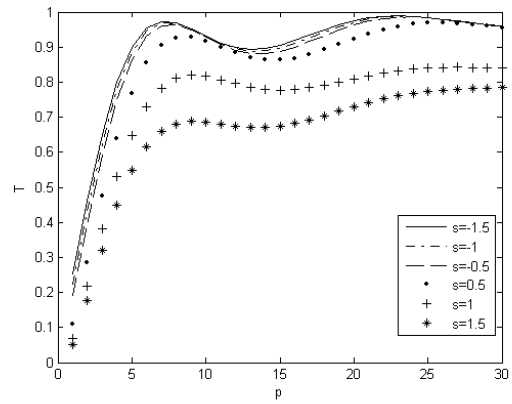

Fig.2 the transmission T of the pulse u_2 for g=-1, s=-1.5,-1,-0.5,0,0.5,1,1.5

In fig.3, it is given that s=1 and g has different values, so it means that the two fibers has same dispersion and their nonlinearity coefficient are different (except g=1). From fig.3 it is found that the switch efficiencies when g<0 are much higher than those when g>0, and the switch threshold powers when g<0 are much lower than those when g>0. So it is inferred that the switch efficiencies when the two fibers have opposite sings of nonlinearity coefficient are much higher than those when they have the same signs. Furthermore, when g<0, bigger |g| is, higher the switch efficiencies are and smaller the switch threshold power are. When g>0, bigger g is, lower the switch efficiencies are and bigger the switch threshold power are.

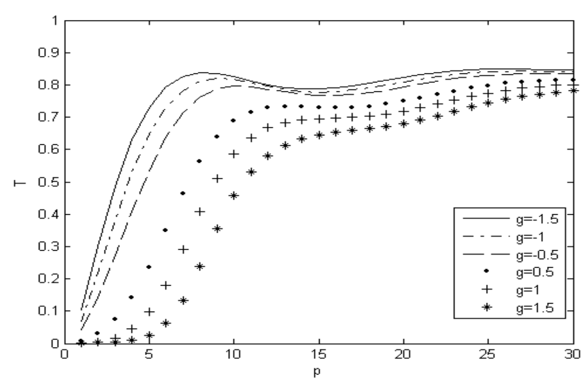

Fig.3 the transmission T of the pulse u_2 for s=1, g=-1.5,-1,-0.5, 0.5,1,1.5

In fig. 4, it is given that s =-1 and g has different values. It means that the dispersion sign of the two fibers is opposite. On the condition above, the switch efficiencies is very high and remains basically constant, and the switch threshold power are different. The result shows that when both of dispersion signs of the two fibers are opposite, the switch efficiencies are much high whether the nonlinearity values of the two fibers are same or not. But the switch threshold power when g<0 is lower than those when g>0.

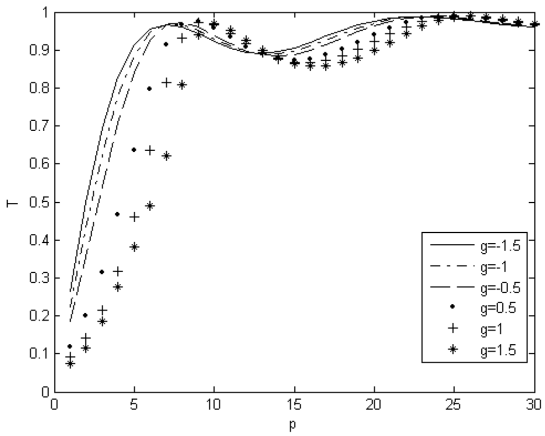

Fig.4 the transmission T of the pulse u_2 for $s=-1, g=-1.5,-1,-0.5, 0.5,1,1.5$

4. Conclusions

In this paper, some useful results are obtained in the frame of our numerical method and it is inferred that higher switch efficiencies and lower switch threshold power can be obtained when the dispersion and nonlinearity of the two fibers are different, especially for the opposite sign of the dispersion. So the asymmetric dual-core coupler has much higher switch efficiencies and lower switch threshold power than the symmetric coupler.

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*Corresponding author: kepxie@mail.mdanderson.org