Effect of the Multiphoton Susceptibility on the Characteristics of Semiconductor Devices

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Received July 12, 1993; revised manuscript received September 17, 1993

Making use of numerical simulations we study the transmission characteristics of a twin core nonlinear directional coupler using a non-Kerr-like nonlinear refractive index semiconductor. Our results suggest that high order multiphoton susceptibility plays an important role in the performance of the device.

I. Introduction

All optical switching devices are attracting considerable interest as fast switching components for future high-bit-rate systems. If materials with fast responding nonlinearities are used, optical devices should operate at far higher rates than the electronic devices.

Optical fibre couplers have been of interest for their potential aplications to ultrafast all optical signal processing, like optical switches. Previous studies of soliton switching in optical fibers couplers have shown excellent switching caracteristics,with switching efficiency aroung 96% for a wide range of input energies[1]. Recently reported results in a fibre with linear and quadratic (non-Kerr) intensity dependent refractive index show the possibility of a bistable solitary wave regime[2].

Such type of nonlinearity can be attributed to various processes, in particular with three-photon susceptibility. The three photon cross section in most materials is very small. However recent results on nonlinear directional couplers made of AlGaAs and AlGaAs/GaAs quantum wells shows that three-photon susceptibility in the quantum well nonlinear directional coupler is much stronger than in bulk waveguides[6]. In this case the multiphoton absorption lead to severe limitations on the switching caracteristics. This effect could also appear in fibres doped with semiconductor nanocrystals. In this kind of material, high values for the nonlinear susceptibilities were reported[3,4,5] with $\chi^{(3)}$ ranging from 10^{-7} to 10^{-12} e.s.u. and the higher order susceptibilities $\chi^{(5)} = 1.8.10^{-14}$ and $\chi^{(7)} = 3.2.10^{-18}$ e.s.u.

In this paper we examine the effect of the non-Kerr like nonlinear index contribution in the behaviour of a twin-core nonlinear directional coupler.

II. Results and discussion

The propagation of ultrashort light pulses in a nonlinear fibre directional coupler can be described in terms of two linearly coupled generalized nonlinear Schrodinger equations. If we denote the mode amplitudes by u and v, and use soliton units[1], we can write

$$i\frac{\partial u}{\partial \xi} = -\frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} - Kv + f(|u|^2)u \tag{1}$$

$$i\frac{\partial v}{\partial \xi} = -\frac{1}{2}\frac{\partial^2 v}{\partial \tau^2} - Ku + f(|v|^2)v \tag{2}$$

where u and v are the modal field amplitudes in soliton units in cores 1 and 2 . ξ and τ are the normalized length and time in soliton units where $\xi = z/L_D$ and $\tau = t/T_0$. Where $L_D = T_0^2/|\beta_2|$, T_0 is the pulse width and β_2 is the dispersion term.

We will consider only the negative case,that corresponds to negative group velocity dispersion. K is the usual coupling coefficient with a normalization involving the soliton caracteristic dispersion length L_D. It can be written as

$$K = \frac{\pi L_D}{2L_c} \tag{3}$$

where L_c is the linear coupling length required for complete transfer of energy from one core to the other. A nonlinear coupler, shown schematically in Fig. 1 consists of two closely spaced, paralell, single mode waveguides in a material with an intensity-dependent index of refraction. Small signals introduced in core (1) transfer completly to core (2) in L_c. Higher intensities induces changes in the refractive index and detune the coupler.

The critical power, $P_c = A\lambda/n_2 L_c$ (where A is the fibre effective mode area, λ is the pump wavelength and n_2 the nonlinear index) is the input power above which light remains primarily confined to the core it was introduced ($P = P_c$ gives 50% transmission).

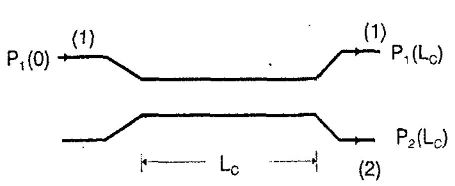

Figure 1: Schematic of a nonlinear coupler.

Starting from Eqs. 1 and 2 we have analyzed numerically the transmission of first-order solitons through the nonlinear fibre coupler. For the ultrashort pulses in which we are interested we define the transmission T in terms of pulse energies:

$$T = \frac{\int_{-\infty}^{+\infty} |u(\xi(z = L_c), \tau)|^2 d\tau}{\int_{-\infty}^{+\infty} |u(0, \tau)|^2 d\tau} \tag{4}$$

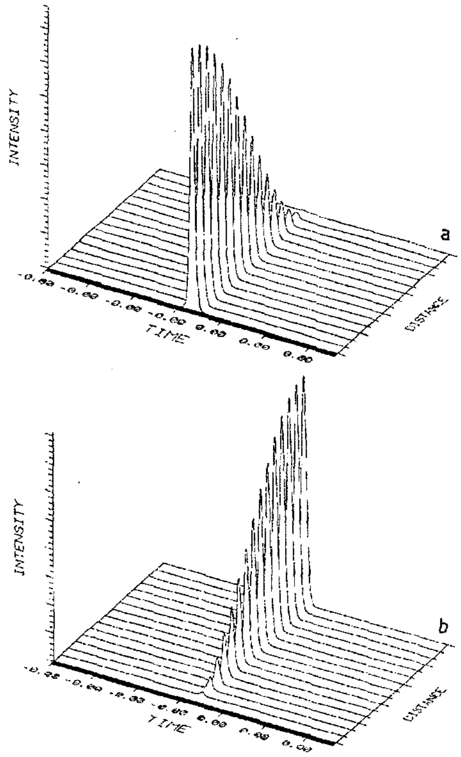

Figure 2: Soliton switching with first order ($N = 1$) solitons as inputs, $K = 1$, $\theta = 0$, $P = 0.34\ P_c$. Low energy soliton is switched from core 1 (a) to core 2 (b) ($\xi = \pi/2$).

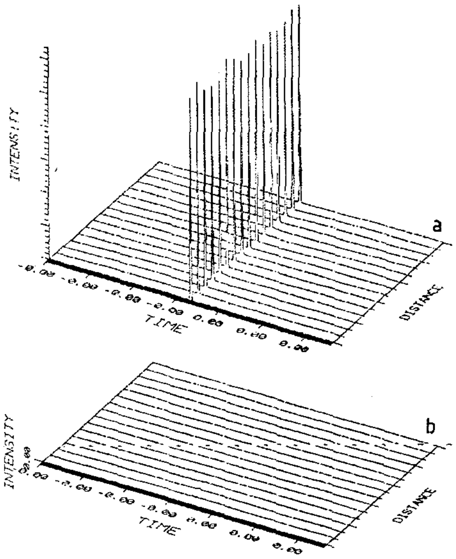

Figure 3: High energy soliton is retained in core 1 (a) .$K = 1$, $\theta = 0$, $P = 2P_c$ and $\xi = \pi/2$.

In our case $f(|q|^2) = \Delta|q|^2 + \theta|q|^4$ ($q = u, v$) with $\theta = -n_4|\beta_2|/T_0^2\gamma$ and $\Delta = -1$, where γ is the Kerr coefficient associated to $\chi^{(3)}$ and n_4 is proportional the high order susceptibility $\chi^{(5)}$.

With negative group velocity dispersion and no coupling ($K = 0$) we have two situations ($\theta = 0$ and $\theta \neq 0$) where analytical solitary waves exists[1,2,7].

For the first situation, the initial pulse at the input core (core 1) is set to be:

$$u_1(0, \tau) = A\ sech\ (A\tau/N) \tag{5}$$

For the second situation ,analytical solutions could be found elsewhere[5]. Figs. 2 and 3 show how a low energy first order soliton and a high energy first order soliton propagate through a $\pi/2$ nonlinear coupler ($\theta = 0$). It is clear that the switched pulses maintain the characteristics of first order solitons. This feature together with the good nonlinear transmission (Fig. 4), should be useful in high speed switching applications. Also in Fig. 4 we have the transmission for $K = 1$ and $\theta = 10^{-3}$, 5.10^{-2}, and 10^{-1}. A very dramatic change in efficiency is observed for $\theta > 10^{-2}$. Fig. (5) shows how a low energy first order soliton ($P < P_c$) propagates in a nonlinear fiber coupler with $\theta = -0.1$. The switching from core (1) to core (2) with complete energy transfer is quite clear. Fig. 6 shows the input pulse (core 1) and switched pulse (core 2) from Fig. 5. The pulse appears with little deformation. This behaviour could be expected because of the nonlinear phase shifts introduced by the coupler that could chirp the phase profile of the optical pulses.

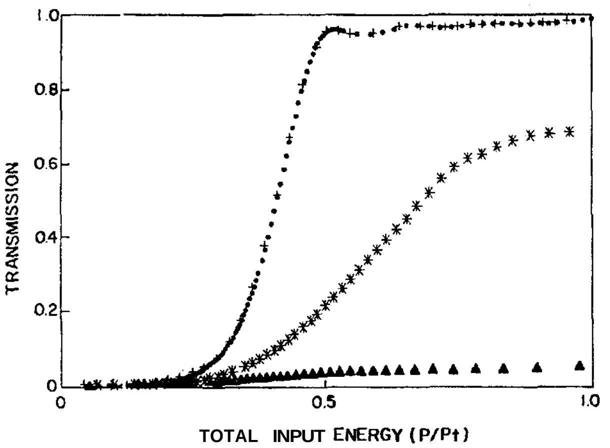

Figure 4: Nonlinear transmission of first order solitons through a $\pi/2$ twin-core nonlinear optical coupler (core 1). The input energy is normalized with $P_t = 2.4P_c$, $K = 1$, (+)e = o, (□)$\theta = 10^{-3}$, (*)e$= 5.10^{-2}$. (n)e $= 10^{-1}$.

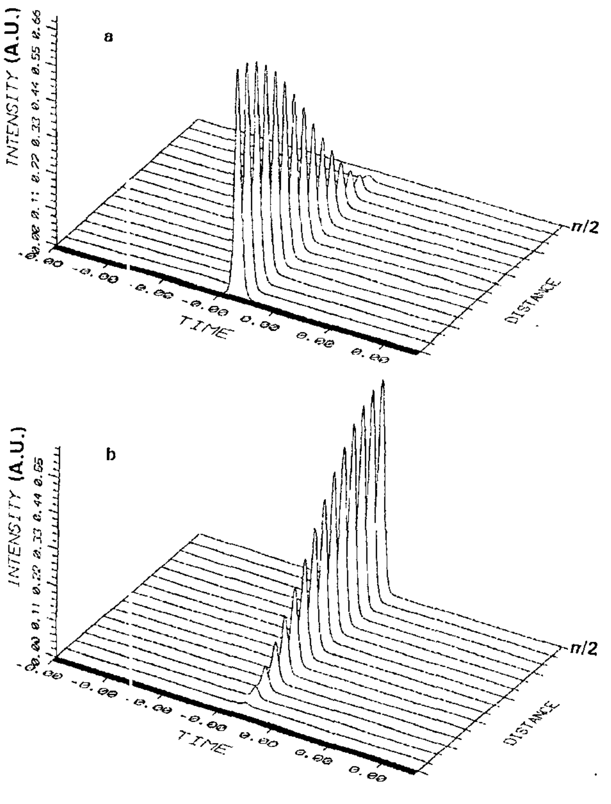

Figure 5: Soliton switching with $K = 1$. $\theta = 10^{-1}$. $p = 0.34P_c$ from core 1 (a) to core (2) (b).

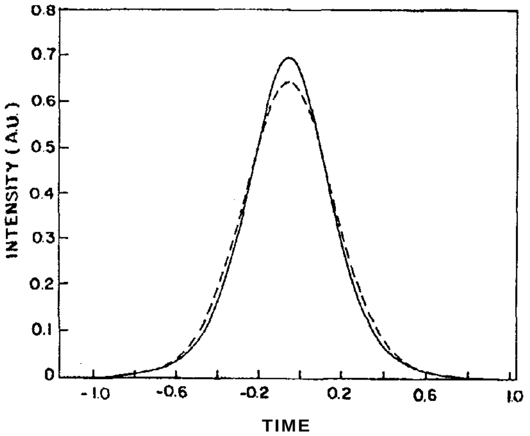

Figure 6: Extract from Fig. 5, (continuous line) input soliton in core 1, (dotted line) switched soliton in core 2.

In Fig. 7 we have the pump and switched pulse in the same configuration as before but with high energy (P> P_c). In this situation the deformation is stronger leading to a pulse compression due to the power discriminatory performance of the coupled waveguide[8].

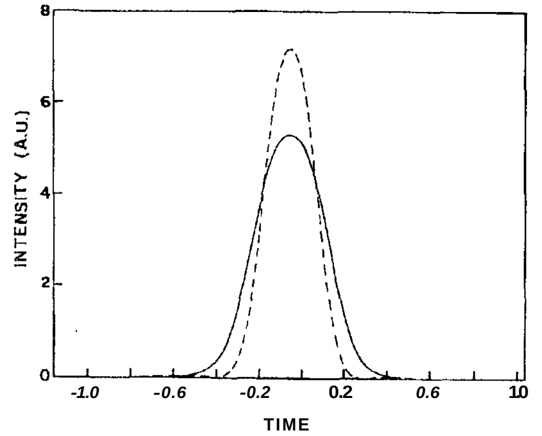

Figure 7: Soliton switching with $K = 1$, $\theta = 10^{-1}$, P = $2P_c$, (continuous line) input soliton in core 1, (dotted line) switched pulse in core 2.

The transmission behaviour of the directional coupler under the effect of this nonlinearity is in agreement with recent results which show that quasi-soliton behaviour could appear under the effect of the multiplioton susceptibility[5]. It was shown (Ref. 5) that the solitary wave solutions from the generalized nonlinear Schrödinger equation are not solitons, because of the partially inelastic collisions observed. Nevertheless these pulses are stable under small perturbations.

These results suggests that the high order effects could destroy the performance of the nonlinear directional coupler and should be taken in account in the future development of these devices.

In conclusion we have reported results concerning the cffect of high order nonlinear index change in the efficiency of a twin core nonlinear directional coupler.

Acknowledgment

I thank CAPES (Brazilian Agency) foi the financial support.

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