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USING A NONLINEAR COUPLER TO SORT A SEQUENCE OF WEAK AND STRONG PULSES

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Abstract. *In this article, the dependence of power transfer coefficient of a nonlinear coupler on its length and the input intensity is investigated and discussed. The nonlinear threshold of the nonlinear coupler is determinated. Based on that, the capacity to select the optical pulses is found out. The sorting of a sequence of weak and strong pulses by the nonlinear coupler is simulated.*
Key words: *Optical fiber, Optical coupler, Kerr effect, Wave coupling.*

I. INTRODUCTION

Normally the cores of both fibers of a coupler are linear (Fig.1a). In this article, we consider the nonlinear coupler where the core of one of the fibers is nonlinear Kerr medium, the other one is linear (Fig.1b).

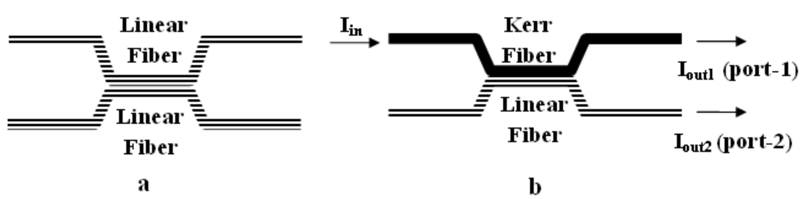

Fig. 1. (**a**) Linear fiber coupler. (**b**) Nonlinear fiber coupler.

As shown in some works [4, 6], the transfer percentage of coupler depends on principle parameters as length of coupler, radius of fiber, and separate space between them. When two waveguides are sufficiently close, light can be coupled from one waveguide to the other [6, 11, 12]. A nonlinear direction coupler works based on this principle. The refractive index and the dimensions of the waveguides may be selected so that when the input optical power is low, it is channeled into the other waveguide; when it is high the refractive index is altered in the nonlinear material and the power remains in the same waveguide.

In this paper we propose nonlinear fiber coupler (see Fig.1b). In Sec.2 from propagating equation of coupling waves [1, 6, 10], we introduce the equation describing the power transferring of nonlinear coupler and investigate the dependence of power transfer coefficient of the nonlinear coupler on its length. In Sec.3 we study on the dependence of the power transferring of nonlinear coupler on the input intensity. The nonlinear threshold of the nonlinear coupler is determinated. In Sec.4 the sorting of the sequence of weak and strong pulses by the nonlinear coupler is simulated and discussed.

II. POWER TRANSFERRING OF NONLINEAR COUPLER

From previous works [10], we have expressions for transferring power between fibers of the nonlinear coupler as follows:

$$\begin{aligned} \eta = \frac{P_1(z)}{P_1(0)} &= 1 - \frac{C^2}{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2} sin^2\left(z\sqrt{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2}\right), \\ 1-\eta = \frac{P_2(z)}{P_1(0)} &= \frac{C^2}{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2} sin^2\left(z\sqrt{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2}\right), \end{aligned} \quad (1)$$

where $1-\eta$ and η is transfer coefficient of power from Kerr fiber to linear fiber and to Kerr fiber, respectively; $P_1(0)$, $P_1(z)$ and $P_2(z)$ are input optical power, optical power of wave in Kerr fiber from port-1 and optical power of wave in linear fiber from port-2, respectively; n_{nl} is the nonlinear coefficient of refractive index of Kerr fiber; C is coupling coefficient; I_{in} is input intensity; λ is wavelength; z is the nonlinear coupler length.

Consider the nonlinear coupler $C = 0.694/mm$ [6], $n_{nl} = 10^{-12} mm^2/W$, the input light wavelength $\lambda = 1.53\mu m$ and the input intensity $I_{in} = 1,4.10^{11}$ W/mm^2; $\epsilon_0 = 8,854.10^{-12} F/m$. From (1) we can see the power transfer coefficient is a periodical function of the nonlinear coupler length (see Fig. 2).

From Fig. 2 we can see corresponding to the input intensity $I_{in} = 1,4.10^{11}$ W/mm^2, the nonlinear coupler still reflect transferred characteristics of a linear coupler, i.e. the power transfer coefficient have value from 0 to 1 for a period. This does not occur in the nonlinear coupler. L_{max} is the nonlinear coupler length corresponding to the transfer coefficient of power from Kerr fiber into linear fiber is about 100 percent. This thing is not occuring when input intensity increases. In fact, when input intensity is high, Kerr effect strong, refractive index in Kerr fiber increases quickly. So the reflection into the Kerr fiber is stronger than into the linear fiber . The simulated result shows that when input intensity $I_{in} \geq 1.5 \times 10^{12} W/mm^2$, the light power in the Kerr fiber cannot channel into the linear fiber, it only transfer into the Kerr fiber (see Fig. 3).

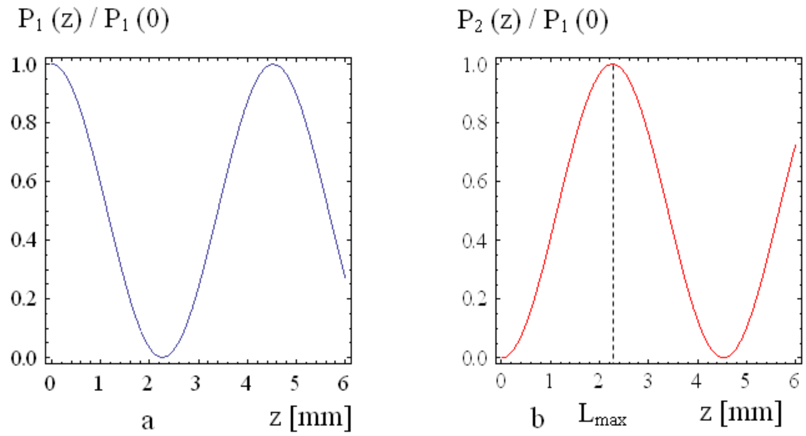

Fig. 2. Periodical transfer of power (**a**) in Kerr fiber. (**b**) in Kerr fiber is channeled into linear fiber of the nonlinear coupler.

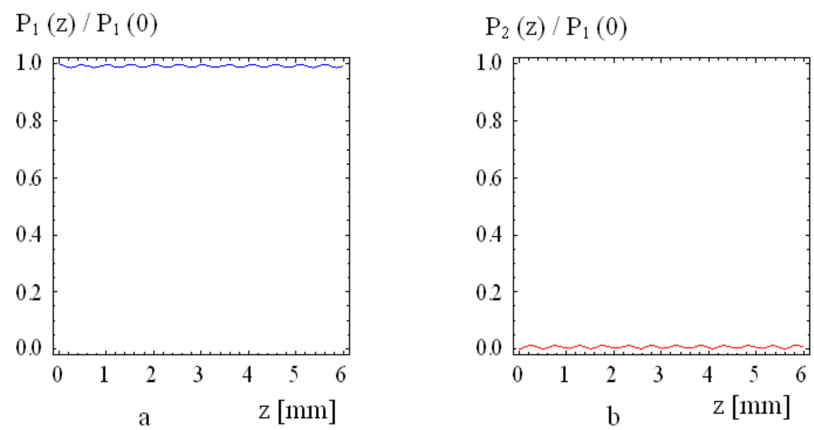

Fig. 3. The power transfer coefficient when $I_{in} \geq 1.5 \times 10^{12} W/mm^2$(**a**) from output port-1. (**b**) from output port-2.

III. THE NONLINEAR THRESHOLD OF A NONLINEAR COUPLER

For the nonlinear coupler with the following parameters: $C = 0.694/mm$ [6], $n_{nl} = 10^{-12} mm^2/W$, $\epsilon_0 = 8,854.10^{-12} F/m$, and the nonlinear coupler length is long $z = L_{max} = 2.3mm$, the dependence of the power transfer coefficient of the nonlinear coupler on the input intensity at wavelength of $\lambda = 1.53\mu m$ is plotted in Fig. 4

Fig. 4 shows that, when input intensity $I_{in} < 1,4.10^{11} W/mm^2$, the light power in Kerr fiber almost is channeled into linear fiber . In this case, the power transfer coefficient of the nonlinear coupler does not depend on input intensity. That is characteristic of the linear coupler. When input intensity increases to

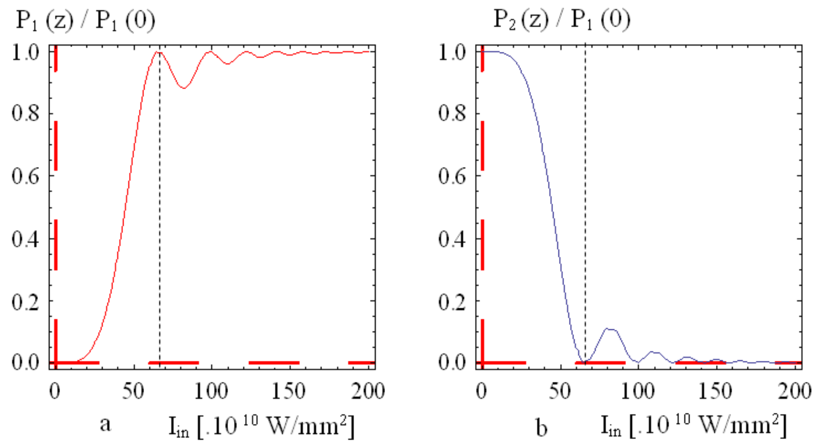

Fig. 4. The power transfer coefficient when $z = L_{max} = 2.3mm$, (**a**) from output port-1. (**b**) from output port-2.

$I_{in} > 1,4.10^{11} W/mm^2$, the Kerr effect occurs. Thus, a part of the light power remains in the Kerr fiber. So, the first nonlinear threshold of the nonlinear coupler is $I_{T1} = 1,4.10^{11} W/mm^2$.

When input intensity increases, the power transfer coefficient from Kerr fiber into linear fiber decreases and the power transfer coefficient into the Kerr fiber increases. When input intensity is high $I_{in} > 1,5.10^{12} W/mm^2$, the light power in Kerr fiber cannot transfer into linear waveguide, but into the Kerr fiber, the power transfer coefficient in Kerr fiber is approximately 100 percent. Thus, the second nonlinear threshold of the nonlinear coupler is $I_{T2} = 1,5.10^{12} W/mm^2$.

From these results, we can conclude that the nonlinear coupler can be used not only as switching and performing logic operations, but also as sorting a sequence of weak and strong pulses, separating them into the two output ports, as illustrated in figure 5.

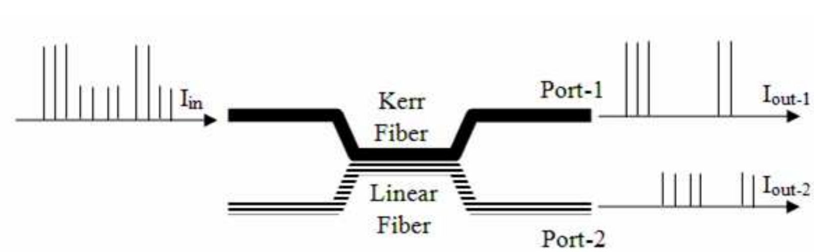

Fig. 5. The sorting of a sequence of weak and strong pulses.

IV. THE SORTING A SEQUENCE OF WEAK AND STRONG PULSES BY THE NONLINEAR COUPLER

In the laser operation, a series of closed to Gaussian pulses with arbitrary amplitude may appear. Mathematically, the dependence of laser intensity on time can be approximately expressed in the form as

$$I_{in}(t) = (I_0 + mkI_m)\, e^{-\left(\frac{\sqrt{ln2}(t-3T-7kT)}{T}\right)^2}, \tag{2}$$

where I_0 is the first amplitude of the series of Gaussian pulses, mI_m is the modulating amplitude, m is random function, k is integer, T is the period of the series of Gaussian pulses.

Numerically solving (2) by Mathematical software using typical parameters: $I_0 = 0.5 \times 10^{11} W/mm^2$, $k = 0, 1, 2, 3, 4, 5, 6$ and t/T is chosen arbitary, the series of input Gaussian pulses are simulated and illustrated in Fig. 6.

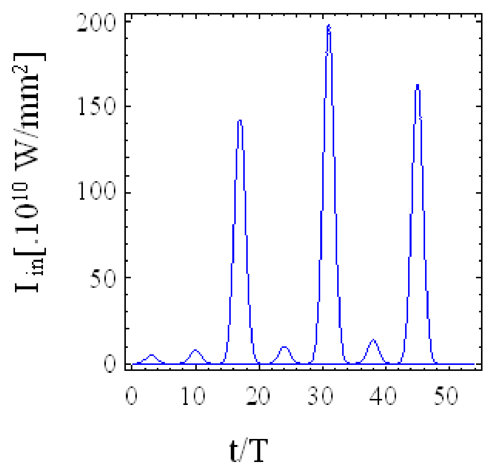

Fig. 6. The series of input Gaussian pulses with arbitrary amplitude.

From equation (1) we have the output-input intensity relation as follows

$$\begin{aligned} I_{out_1} =& I_{in}\left[1 - \frac{C^2}{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2} sin^2\left(z\sqrt{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2}\right)\right], \\ I_{out_1} =& I_{in}\left[\frac{C^2}{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2} sin^2\left(z\sqrt{\frac{4\pi^2 c^2 \epsilon_0^2 n_{nl}^4 I_{in}^4}{16\lambda^2} + C^2}\right)\right]. \end{aligned} \tag{3}$$

Substituting (2) into (3) and using by Mathematical software for the nonlinear coupler, with typical parameters: $C = 0.694/mm$ [6], $n_{nl} = 10^{-12} mm^2/W$, $\epsilon_0 = 8,854.10^{-12} F/m$, $z = L_{max} = 2.3mm$, $\lambda = 1.53\mu m$ and t/T is chosen arbitary, the series of output pulses from output port-1 and output port-2 are simulated and illustrated in Fig. 7.

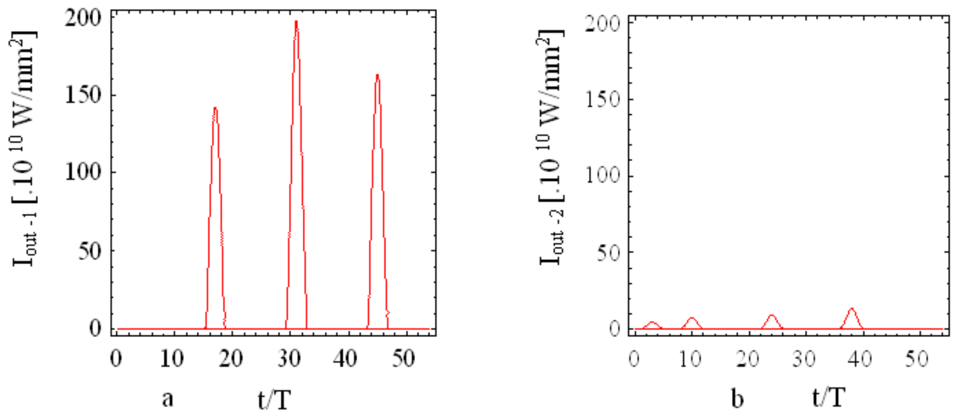

Fig. 7. a) The series of strong output pulses from output port-1. **b**) The series of weak output pulses from output port-2.

Though the peaks of input pulses change randomly causing by the random function (see Fig. 6), but by the nonlinear coupler, from Fig.7 we can see that, the input pulses with low peaks, $I_{in} \leq I_{T1} = 1,4.10^{11} W/mm^2$, transfer into linear fiber from output port-2; the input pulses having high peaks, $I_{in} \geq I_{T2} = 1.5 \times 10^{12} W/mm^2$, remain in the Kerr fiber from output port-1.

V. CONCLUSION

In this report we have shown the dependence of the power transfer coefficient of a nonlinear coupler on the nonlinear coupler length is periodic and the maximum length of nonlinear coupler L_{max} is derived. We have obtaired the dependence of the power transfer coefficient of a nonlinear coupler on the input intensity, that allows to derive the nonlinear threshold of a nonlinear coupler. The obtained results of simulation show that the nonlinear coupler can be used not only to switch and to perform as a logic gate but also to sort a sequence of weak and strong pulses, separating them from its output ports.

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