Self-Switching Using SOA-Assisted Sagnac Interferometer

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Abstract—**We propose and investigate self-switching mechanism by Sagnac interferometer based semiconductor optical amplifier (SOA) for subpicosecond pulses. The various switch characteristics such as phase differentiation between propagated pulses, SOA gain and switch extinction ratio all in time domain are shown.**

I. INTRODUCTION

The switching characteristics of SOA as a nonlinear component in all-optical networks have been of large attention in recent researches. Sagnac switch based on SOA is one of favorite structures to achieve this goal. By using modified nonlinear Schrödinger equation (MNSLE) considering main which includes nonlinear effects, we study gain and phase dynamics of SOA. The analysis is based on improved finite difference beam propagation method (IFD-BPM) [1]. In Sagnac loop, cross phase modulation (XPM) technique is used by employing SOA switching nonlinearities [2,3]. The input light pulse enters the first loop through input port of input coupler and splits unequally into two counter-propagating pulses, (u and v), with $\pi/2$ phase difference. In our proposed scheme, SOA is offset from the center of the loop using optical delay line (ODL). This will cause SOA to operate in different regimes for two input pulses. This phenomena, if other Sagnac switch parameters are tuned suitably can lead to sufficient phase difference between SOA's output counter-propagating pulses required for proper switching mechanism. Nonlinear effects of SOA become more important in subpicosecond regime rather than in the picoseconds regime. The main nonlinear effects are: self phase modulation (SPM), two photon absorption (TPA), carrier heating (CH), spectral hole burning (SHB), Kerr effects and gain dispersion. In subpicosecond regime, besides SPM effect which is the dominant phenomenon for picosecond pulses, the effects of SHB and CH phenomena on pulse shape and spectrum are more noticeable. Due to these effects the switch output pulse is broadened. In comparison to previous works [2,3] in our proposed scheme we don't need additional pump pulse for switching purpose besides using two independent input and output couplers, which leads to more tunability. Furthermore the double Sagnac structure with symmetric output coupler (coupling ratio 0.5) can be used as a pattern effect compensator [4].

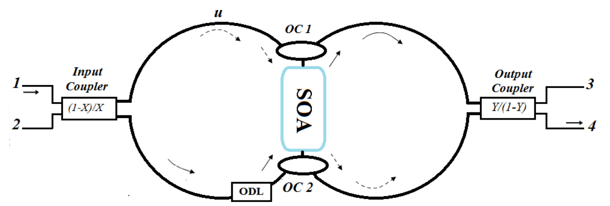

Fig.1. Schematic of Sagnac-based switch with unequal power distribution due to 2×2 couplers. OC: optical circulator, ODL: optical delay line.

II. THEORY

A. *Self-switching Operation Perinciple*

The operation of the self- switching can be described with the help of the schematic diagram shown in Fig. 1. The switch consists of two optical loops formed by the joint input and output ports of two independent 2×2 couplers and a SOA that can be offset from the midpoint of the loops. When an input pulse enters the loop through one of the input ports of input coupler, it splits asymmetrically to two counter-propagating pulses, (u and v). Each coupler induces a $\pi/2$ phase difference between its outputs. The low power optical pulse is injected several picoseconds before the high power optical pulse. These delays cause changes in both gain and refractive index of SOA for two counter-propagating pulses and therefore, propagating pulses experiences different dynamic states. As a result, due to SOA nonlinearities the phase difference occurs between these two pulses.

B. *Theory of proposed self-switched scheme*

The optical input pulse injected in one of the input ports [e.g., Port 1, see Fig. 1], is distributed unequally to u and v pulses. The power splitting ratios in input and output coupler are X and 1-Y, respectively. The u and v pulse powers after passing through input coupler are $p_u = XP_{in}$ and $p_v = (1\text{-}X)P_{in}$ respectively, where P_{in} is input power. The high power optical pulse arrives 7 ps (the time needed for a pulse propagated through the SOA cavity) after the low power optical pulse. As mentioned before, SOA induces a nonlinear phase shift ($\Delta\varphi_{NL}$) to optical pulses. When $\Delta\varphi_{NL} = \pi$, maximum extinction ratio between switch outputs (Port 3 and Port 4) can be reached. The basic interferometric equations that describe the output pulses at the output ports (P3 and P4 respectively), can be written as

$$P3 = YP_u(t) + (1-Y)P_v(t) + 2 \times (\sqrt{Y(1-Y)P_u(t)P_v(t)} \times cos[\varphi_u(t) - \varphi_v(t)]) \quad (1)$$

and

$$P4 = (1-Y)P_u(t) + YP_v(t) - 2 \times (\sqrt{Y(1-Y)P_u(t)P_v(t)} \times cos[\varphi_u(t) - \varphi_v(t)]) \qquad (2)$$

where $P_u(t)$ and $P_v(t)$ are powers of the u and v pulses after passing through the SOA and $\varphi_u(t)$ and $\varphi_v(t)$ are the corresponding phase shifts. These two parameters are related to $\Delta\varphi_{NL}$ by

$$\Delta\varphi_{NL} = \varphi_u(t) - \varphi_v(t) = -\frac{\alpha_N}{2} ln\left(\frac{G_u(t)}{G_v(t)}\right) \qquad (3)$$

where $G_u(t)$ and $G_v(t)$ are the SOA gain sensed by the u and v pulses and α_N is the linewidth enhancement factor associated with the gain changes due to carrier depletion.

C. SOA Model

To take into account all nonlinear effects in the SOA, a set of MNLSEs are solved numerically. The analysis is based on central difference approximation in time domain and trapezoidal integration technique for spatial steps [1].

III. RESULTS

In our simulation, the SOA has a length of 500 µm with operating wavelength at 1550 nm. The asymmetric couplers are obtained by using an unbalanced multi-mode interference (MMI) devices with a coupling ratio $X = Y = 0.3$. The input pulse shape is $sech^2$ and Fourier transform limited with 200 fs full width at half maximum (FWHM) and input energy is equal to 1 pj. The variation of phase difference and its cosine with time at $g_0 = 78.5\ cm^{-1}$ (which is related to amplifier bias current [1]) are shown in Fig. 2. It is shown that for specific time spans, $\Delta\varphi_{NL}$ between two pulses reaches π. Fig. 3 shows the time evaluation of SOA's gain sensed by each pulse, for the same g_0. The solid line is SOA gain variation at u pulse input facet and dashed line is SOA gain variation at v pulse input facet. The two dip structures shown in this figure are due to time delay between u and v pulses. The shallow dip in solid line curve is related to input u pulse and the deep dips corresponds to output v pulse. In dashed line curve the sallow hole is due to output u pulse and the deep dip corresponds to input v pulse. The switching characteristic of our structure is plotted in Fig. 4. The effect of g_0 on extinction ratio (P4/P3 by use of (1) and (2)) is illustrated in Fig. 4. For g_0 less than 40

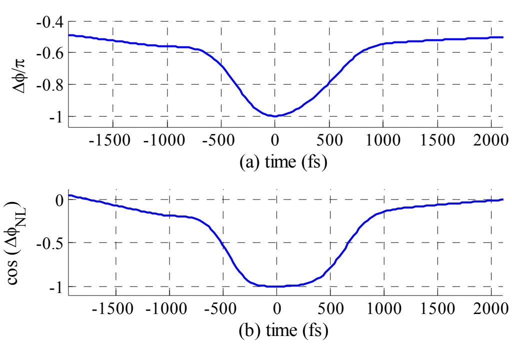

Fig.2 (a) Variation of phase difference between two pulses, (b) Time variation of cos($\Delta\varphi_{NL}$).

is transmitted to port 4 (switching port) and the switching function will be achieved.

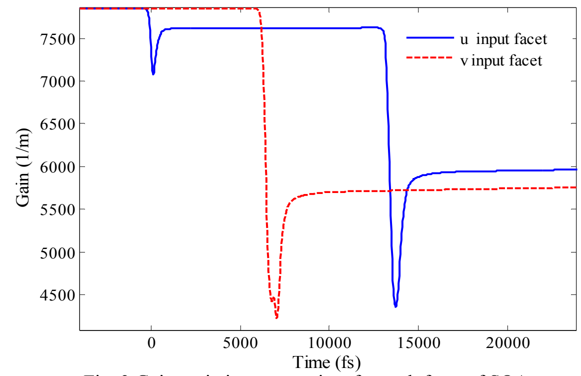

Fig. 3 Gain variation versus time for each facet of SOA.

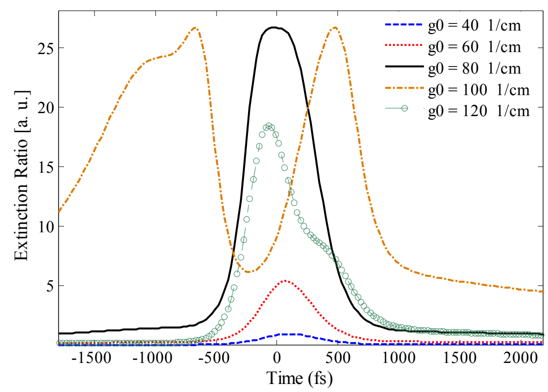

Fig.4 Extinction ratio for various values of small signal gain (g_0) versus time.

IV. CONCLUSION

We numerically analyzed self switching mechanism in SOA-assisted Sagnac interferometer by unequal distribution of input optical pulse. We showed that the switching function in our proposed scheme can be accomplished by varying the SOA's bias current.

ACKNOWLEDGMENT

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