Experimental Analysis of All Optical NOT gate and Latch based on an Externally Clamped Semiconductor Optical Amplifier

Sergio L. Stevan Jr and António L. J. Teixeira

***Abstract* — An all-optical NOT gate is experimentally demonstrated recurring to external gain clamping of a semiconductor optical amplifier. Latch principle is subsequently demonstrated with the aid of an optical ring laser, using off-the-shelf devices.**

***Index Terms* — NOT Gate, SOA, Optical Latch**

I. Introduction

SEMICONDUCTOR Optical Amplifiers (SOA) are all-optical amplification devices that have been widely used in different applications. In special, they can be used as optical gates and other all-optical logical devices in very simple ways, like gain compression [1]. However, the speed and relation between the 'on' and 'off' state in the latter strategy is limited. Therefore, other processes, which could help the execution of higher speed switching, should be employed [2], and the integration is fundamental, that results at several costs [3].

Gain clamping is frequently used for improving gain linearity and saturation power [4]. Gain clamping is automatic gain control scheme obtained inducing a lasing effect though a resonant cavity formed by a pair of reflective devices, e.g. Fiber Bragg gratings at wavelength close to the range of signal wavelength. This laser effect will use the excess gain available when channel power is varied, maintaining the gain constant over a larger power range. The internal laser power was used as a reservoir of optical energy that extends the linear gain range before gain compression. When the laser energy is consumed laser action turns off [5]. With an adequate project of the reflective devices and their optimum couple at the SOA can be obtained a NOT gate of a signal extern with the control of the internal laser power.

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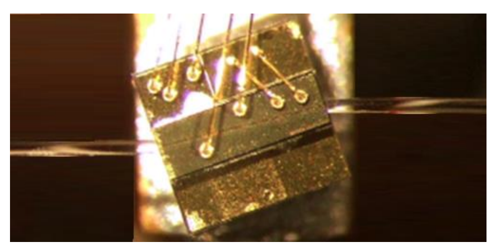
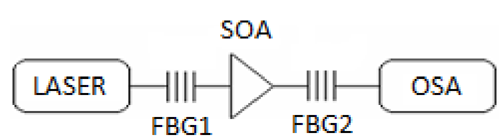
This paper presents an all-optical latch principle, based on Gain-Clamped SOA (GC-SOA) using commercial off-the-shelf devices of low cost [5]. Due to lack of available devices in the laboratory, in special, the existence of only a pair of nanopositioners, a SOA ring laser was build and it was coupled after the GC-SOA to demonstrate the digital all-optical latch principle.

II. Setup and Results

Figure 1 a) shows the setup of the optical NOT gate based on Gain Clamped-SOA, using off-the-shelf devices. The active device is a commercial C-band Booster Optical Amplifier Chip, with several specific characteristics, in special, the angles of coupling, where the lateral beam exit angle are 19.5º [6]. The gain chip was fixed in a nanopositioner and a laser current controller is set to 280 mA. The pair of FBG, centered at 1544.9 nm were recorded near of the end of the fibers, and carefully aligned with nanopositioners as close as possible of the SOA to the light to be coupled at the two sides, as shown in the schematic of the figure 1 b). This process is critical to couple the maximum signal on the fibers, and the fiber's signal to SOA, and consequently the losses due reflections, attenuations and performance of the GC-SOA is very dependent of this couple.



(a)



(b)

Figure 1: (a) NOT gate setup: Optical SOA chip aligned with related FBGs; and (b) simply schematic diagram of the gate.

Figure 2 presents the reflectivity spectrums of the pair of FBG used. These gratings were used with the central wavelength closest available, about 1544,97 nm, and the 3 dB bandwidth are approximately 0,090 nm to FBG1 and 0,120 nm to FBG2, with reflectivities about 50%.

In order to test the saturation effect of the internal laser, showing therefore its erasure, an external laser at 1552 nm was coupled in one of the fibers and your power was varied from -7 dBm to +4 dBm. In the other side, an Optical Spectrum Analyser (OSA) was coupled to verify the evolution of the external and the internal laser powers. With this measurement, one can notice that there is an input Power range where an increase of 2 dB, from 0 dBm to 2 dBm, in the input laser power resulted in an extinction of about 20 dB of the internal laser. This behaviour can be seen in Figure 3, where the output peak power of the external laser (dotted line, at 1552 nm) and the internal laser (solid line, at 1544 nm) varying as a function of the change in input power of external laser. The OSA resolution used was set at 0.2 nm.

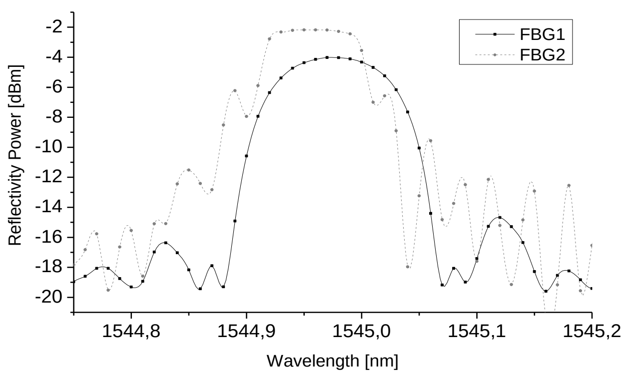


Figure 2: Spectrum of the pair of FBG used on design of Optical NOT Gate setup with SOA.

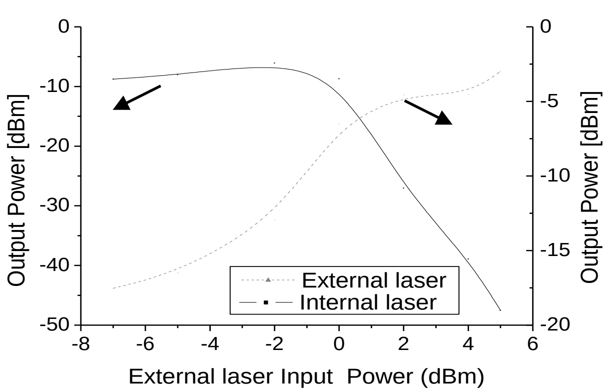


Figure 3: Output powers of the external and internal laser as a function of the external laser subsystem input Power.

Due of laboratory limitations (only a pair of nanopositioners was available), a SOA ring based laser was by us designed using isolators, a SOA and an optical filter available based on FBG centered at 1550 nm, shown in figure 4. The bandwidth of the filter used is about 0,5 nm. The ring laser has about 3 meters of the fiber, resulting in a large resonant cavity and consequently slow response time laser [7]. Figure 5 presents the internal laser power control based on the power variation of external laser

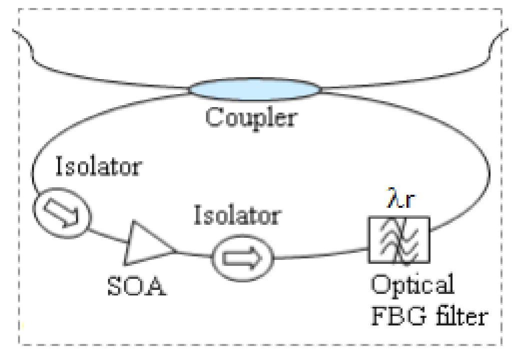


Figure 4: laser ring SOA setup.

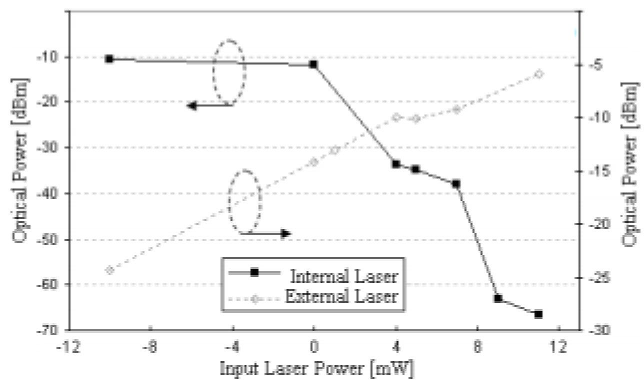


Figure 5: Output powers of the external and internal laser as a function of the external laser subsystem input power on laser ring SOA.

In a second moment, the SOA ring laser had been coupled to the GC-SOA to demonstrate the optical latch operation, as shown in the figure 4 (a). In this new setup, a power variable external laser (PE) was set at 1542 nm and coupled to the input of the GC-SOA (with internal laser at wavelength λw). On the other side of the GC-SOA, a FBG with central wavelength marked as λpe (same of the PE) reflects PE and isolating the next stage. This FBG (λpe) is coupled to the input of a ring laser SOA (based in an optical filter of wavelength λr), and the output is connected in an optical spectrum analyzer (OSA), as shown in Figure 6.

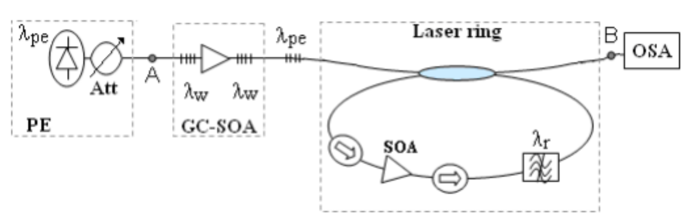


Figure 6: Experimental setup to demonstrate the digital all-optical latch principle

The experimental results are presented in Figure 7, where, in figure 7 (a) are presented the OSA optical spectrum, when the external laser ‘λpe’ is on the state ‘off’, the internal laser of the wafer gain semiconductor ‘λw’ is on the state ‘on’ erasing the internal ring laser ‘λr’. When the external laser ‘λpe’ is on state ‘on’, it erases the laser ‘λw’ and consequently brings to the ‘on’ state laser ‘λr’, as shown in figure 7 (b). This stage should be kept stable even after turning off the laser ‘λpe’, as shown in figure 7 (c).

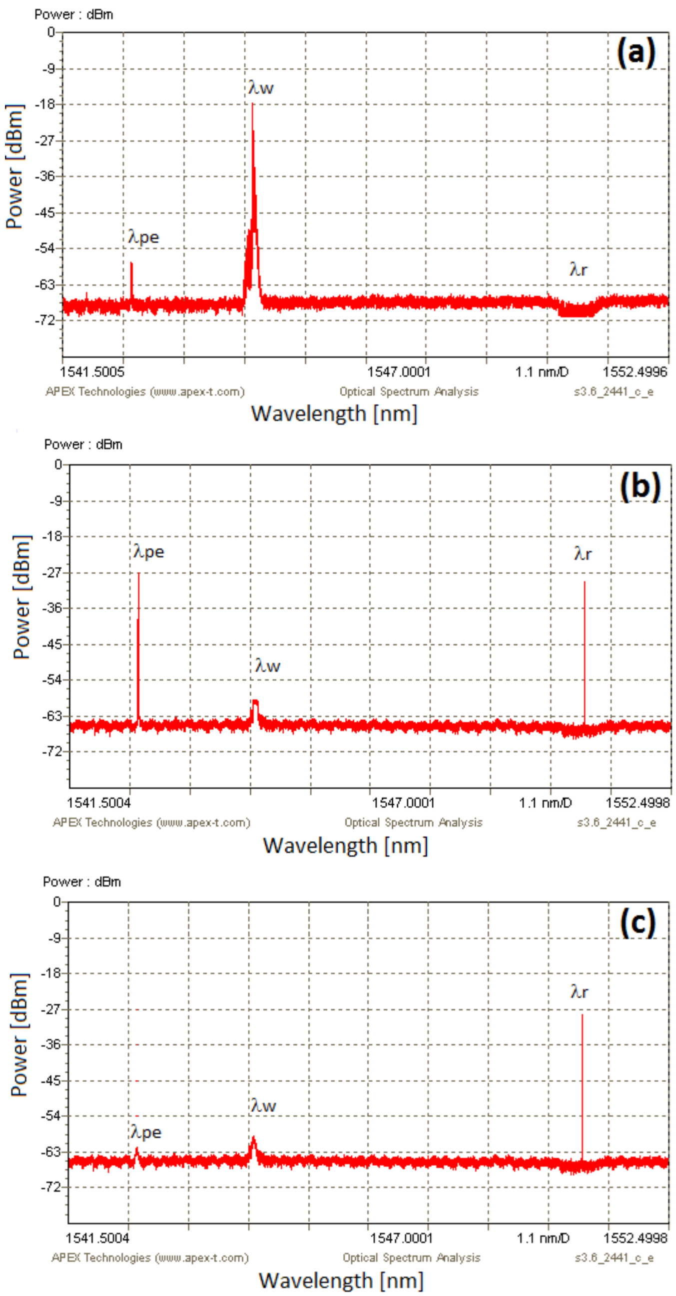


Figure 7: Demonstration of the digital all-optical latch principle, where: (a) Spectra of internal lasers λw ‘on’ and λr ‘off’ a initial state with External laser λpe ‘off’; (b) Spectra induced of internal lasers λw ‘off’ and λr ‘on’ after External laser λpe changes to state ‘on’; and, (c) Spectra of internal lasers λw and λpe without state changes after the External laser λpe ‘off’.

To illustrate the response time of the proposed optical device based on off-the-shelf components, we present in Figure 8, the optical NOT gate based on GC-SOA (from Figure 1), operating at 1.244 GHz and in Figure 9, operating at 5.33 GHz to demonstrate the possible rate of working of the proposed optical device.

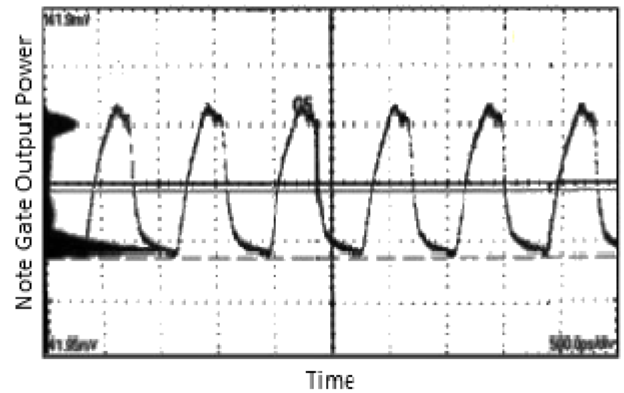


Figure 8 – Response time of the NOT gate to 1.244 GHz with about 5.5 dB of ratio extinction

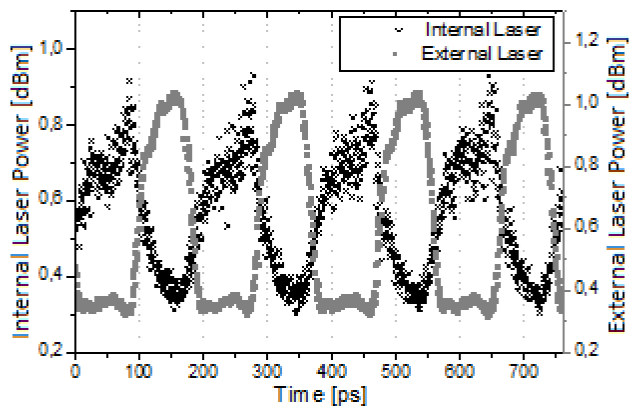


Figure 9 – Response time of the NOT gate to 5.33 GHz, with about 3.5 dB of ration extinction of internal laser.

In Figure 8 is presented the optical behaviour of the internal laser modulated at 1.244 GHz, witch improve an extinction rate of 5.5 dB. The Figure 9 shows the external laser input modulated at 5.33 GHz and the behavior of the internal laser, with extinction rate is about 3.5 dB. This last case represents the maximum rate admitted in this experience. However, this obtained modulation rate can be extended optimizing the characteristics of the experience, as optical alignment and the optical coupling quality on the stages of the setup.

III. Conclusion

We reported experimental results from a Gain-clamped Semiconductor Optical Amplifier using discrete off-the-shelf components. The results showed that a small increase in the external controlling laser power (about 2 dB), when near the gain saturation range of the gain chip, results in a quick erasure of the internal laser (about 30 dB), resulting in a good extinction NOT gate. The latch principle has been demonstrated partially using an additional SOA ring laser. The response time of the latch is the same order of the NOT gate. We obtain the maximum internal' toggling rate of 5.33 GHz with the extinction rate of about 3.5 dB. The demonstration of the logic principles using commercial off-the-shelf components confirm the purpose to take for simple and low cost optical processors, where the couple optimization and incremental laboratory facilities available rightly will reach faster results.

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