All-optical set and reset of semiconductor-optical-amplifier-based flip-flop

Drew N. Maywar, Yoshiaki Nakano, and Govind P. Agrawal†

Dept. of Electronic Engineering
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo 113 Japan
tel: (+81) 3 - 5841 - 6652
fax: (+81) 3 - 5841 - 7752
maywar@optics.rochester.edu
nakano@ee.t.u-tokyo.ac.jp

† The Institute of Optics
University of Rochester
Rochester, NY 14627 USA
tel: (716) 275 - 4846
fax: (716) 244 - 4936
gpa@optics.rochester.edu

Introduction

The bistable behavior of optical signals propagating through resonant-type semiconductor optical amplifiers (SOAs) has been used to demonstrate a wide variety applications to optical communication system. Among these include optical switching [1], wavelength-division demultiplexing [2], signal-regeneration [3], power limiting [4], optical logic [5], and memory [4, 6]. These devices are useful for lightwave systems because they are compact, can be fabricated at any signal wavelength, and exhibit inherent amplification and therefore high fan-out and high cascadability [5].

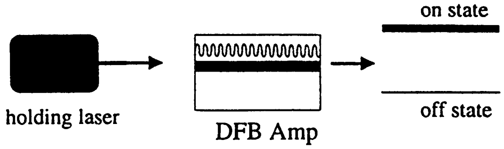
All-optical switching occurs in resonant-type SOAs when the incident pulse power reaches the critical value needed to seed optical bistability. The output power then switches from one stable branch to the other. Switching in these devices has been measured at *microwatt* power levels [7]. Thus, these devices easily operate at power levels available in lightwave systems. Since typical switching speeds are ~ 1 ns, switching occurs at femtojoule energies (~ 7000 photons) [8].

These switching characteristics manifest in the other applications noted above. In particular, the holding beam used for optical memory can operate at microwatt power levels and experiences amplification. An optical memory scheme using such a holding beam is depicted in Fig. 1. Once switched to the upper state, the output power of the holding beam remains high until reset.

The small size and integratability of SOAs [9] allow, in principle, the fabrication of monolithic optical buffers. Such devices would be more compact than fiber-delay lines. An array of 32 amplifiers can be used for storing the packet header required for routing signals through a cross-connect optical circuit.

To make this kind of optical memory viable, there must be a way to all-optically set and reset the holding beam power between stable states. We present new all-optical mechanisms for this application, and present preliminary experimental evidence of operation.

Reprinted from Optical Amplifiers and Their Applications Conference, 1999 Technical Digest, ©1999 Optical Society of America



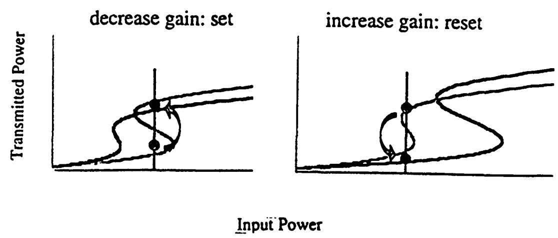


Fig. 1 Optical Memory in Resonant-Type Amplifiers

Fig. 2 Hysteresis Tuning

All-Optical Set and Reset

One way to switch the holding-beam power to the higher stable branch is by momentarily increasing its input power [6] until it surpasses the upper switching threshold. In a similar manner, the switch down from the upper state can be achieved be decreasing the input power.

We propose to set and reset the holding beam by varying the hysteresis itself, while keeping the input power fixed. One way to change the hysteresis is by varying the gain in the amplifier [10]. By increasing the gain, the switching powers of the hysteresis increase. This phenomenon can be understood as follows. An increase in gain in active semiconductors is accompanied by a decrease in the refractive index as embodied by the well-known linewidth enhancement factor. This decrease in refractive index moves the Bragg resonances of the amplifier to shorter wavelengths, and away from the optical signal. Since the signal is farther from the resonance, it require more power to seed bistable switching.

A CW-holding beam will switch between lower to higher branches as the switching threshold of the hysteresis cross the input power of the holding beam. In particular, we can set and rest the holding beam with the configuration shown in Fig. 2. The holding beam begins on the lower branch and in the middle of a hysteresis. A transient decrease in gain pushes the hysteresis to smaller switching powers, allowing the holding beam to switch to the higher branch, where it remains even after the gain recovers. To reset the holding-beam output state, the gain is transiently increased. This pushes the hysteresis to higher powers, and allows the holding beam to switch back down toe the lower branch. Once the increase in gain dies off, the output power returns to its original output state.

A decrease in gain can be achieved *optically* via gain saturation caused by a signal with any wavelength that falls without the gain spectrum of the amplifier. Such a set process is ideal for WDM systems. We also stress that the data signal itself is used directly to set the flip-flop. The holding beam 'remembers' the occurrence of the data signal until it is reset by an increase in gain. An increase in gain can be achieved *optically* via gain pumping by a signal that is absorbed by the amplifier. Such a signal can be sent at regular intervals and act as a clock for the memory system.

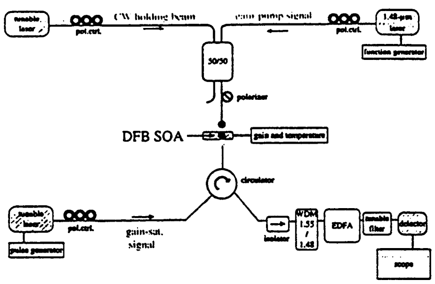


Fig. 3 Experimental System

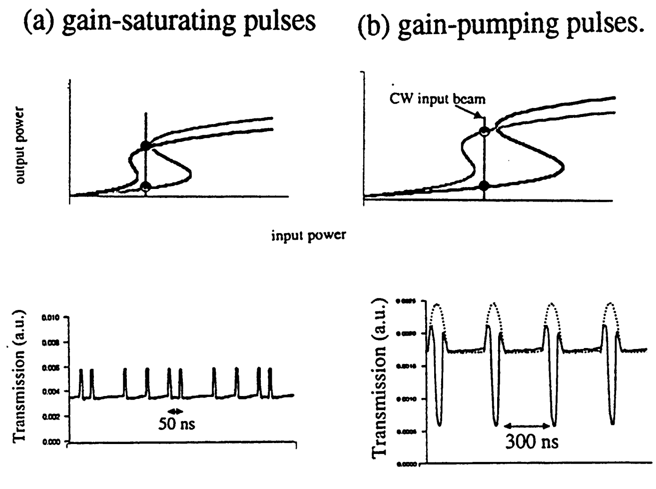


Fig. 4 Wavelength conversion

Experiments

Our experimental system is shown in Fig. 3. To test the affect of gain-pumping and gain-saturating optical signals on the bistable hysteresis, we first performed experiments using exclusively set or reset pulses. Since memory is not easily viewed in this scenario, we looked for wavelength conversion.

The holding beam is tuned out of the bistable region and to lower powers than the switching thresholds of the bistable hysteresis. Using gain-saturating pulses, we transiently shifted the hysteresis completely through the holding beam. The output power of the holding beam switched up and down accordingly. This behavior and experimental result is shown in fig 4a

This new type of noninverted wavelength conversion occurs at optical powers on the order of 10 μW. We operated this configuration with the gain-saturating signals travelling in a co- and counter-propagating direction with the holding beam, and for a variety of wavelengths.

Next, we tested the effect of gain-*pumping* signal by tuning the input power of the holding beam *higher* than the switching thresholds of the bistable hysteresis. Using gain-pumping pulses, we transiently shifted the hysteresis completely through the holding beam. The output power of the holding beam switched down and up accordingly, as shown in Fig. 4b. For these experiments we used a commercially available 1.48-μm laser as our pump. Wavelength conversion occurs at optical powers on the order of 100 μW. We also operated this configuration with the gain-pumping signals propagating co- and counter-directionally with the holding beam.

Using both types of optical signals in tandem, we then tested optical flip-flop operation. Our preliminary experimental evidence of this all-optical flip-flop is shown in Fig. 5. Part (a) shows the case for which there is *no* memory; the set pulse passes through the amplifiers and has no lasting effect on the transmission state of the holding beam. Figure 5b however exhibits memory of the set pulse. The off and on states before and after the set pulse (respectively) are distinct.

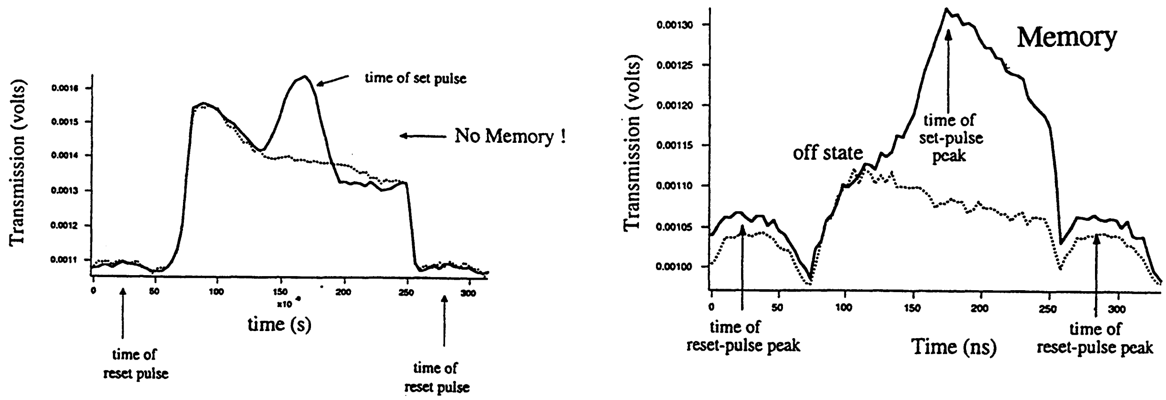


Fig. 5 (a) No Optical Memory (b) Optical Memory

Conclusion

We have demonstrated a new way to optically set and rest bistable memory in a resonant-type SOA. The set pulse can operate at low optical powers (~ 10 μW) and over a wide range of wavelengths (> 40 nm). Thus, the optical signals in WDM lightwave systems can be used directly to set the memory. The reset requires higher optical powers (~ 100 μW), but is easily achievable with commercial 1.48-μm EDFA pump diode lasers. We are currently improving our measurement techniques and planning ways to monolithically integrate these flip-flops.

References

[1] K. Otsuka and S. Kobayashi, Electron. Lett. **19**, 262 (1983).

[2] Z. Pan and M. Dagenais, IEEE Photon. Tech. Lett. **4**, 1054 (1992).

[3] R. P. Webb, Opt. Quantum Electron. **19**, S57 (1987).

[4] N. Ogasawara and R. Ito, Jpn. J. Appl. Phys. **25**, 739 (1986).

[5] W. F. Sharfin and M. Dagenais, Appl. Phys. Lett. **48**, 1510 (1986).

[6] K. Inoue, Optics Lett. **12**, 918 (1987).

[7] H. J. Westlake, M. J. Adams, and M. J. O'Mahony, Electron. Lett. **21**, 992 (1985).

[8] W. F. Sharfin and M. Dagenais, Appl. Phys. Lett. **48**, 321 (1986).

[9] K. Tada and Y. Nakano, Electron. Commun. Japan **77**, 238--249 (1994).

[10] D. N. Maywar and G. P. Agrawal, IEEE J. Quantum Electron. **33**, 2029 (1997).