All-Optical 2R Regeneration Using a Non-Linear Vertical Cavity Semiconductor Optical Amplifier

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Abstract: All-optical 2R logic regeneration is demonstrated using a vertical cavity semiconductor optical amplifier. The optical switching threshold is 1 µW, with 10 dB gain and >6:1 (8dB) extinction ratio. Performance limits are also discussed.

1. Introduction
Signal regeneration is an important part of optical communication links, particularly fiber-optic communications, in order to reduce the accumulation of amplifier noise and signal distortion due to dispersion. Typically, this function is performed electrically, which requires converting the optical signal to electrical and back again for retransmission. There is significant interest in bypassing this conversion and performing all-optical signal regeneration. The two main benefits to all-optical signal regeneration are the potential to increase the bitrate and transmission length, and perhaps more importantly, to reduce the complexity and cost of performing signal regeneration. The two simplest operations are re-amplification and reshaping, or 2R regeneration. The most common method in the literature is to use interferometers with semiconductor optical amplifiers (SOA) in the arms, and utilize cross-phase and/or cross-gain modulation to perform regeneration[1-3]. These systems typically are quite complex, and often use a second laser source or cascaded stages[1].

In this paper, it is shown that a non-linear vertical cavity semiconductor optical amplifier (VCSOA) may be used to perform all-optical 2R logic regeneration. VCSOAs have been demonstrated at all communication wavelengths[4-6], are easily coupled to fiber because of their circular geometry, and can be fabricated in 2-D arrays. Under the proper operating conditions, VCSOAs exhibit a highly non-linear optical transfer function[7]. The non-linear transfer curve of the VCSOA is due to the change in refractive index affected when the optical signal is injected and reduces the carrier concentration via stimulated emission. When the wavelength of the injected light is on the long wavelength side of the resonance, the carrier consumption shifts the resonant point toward the input wavelength. This positive feedback loop results in differential gain and optical bistability. The observed differential gain transfer characteristic satisfies the requirements to be a regenerative logic element, and we have demonstrated an all-optical AND gate based on this non-linearity [8]. Here, we present the first experimental demonstration of a VCSOA performing all-optical 2R logic regeneration. Performance comparisons to interferometric regeneration systems are also discussed.

2. Experimental Results and Discussion
A tunable, external cavity DBR laser is coupled to the VCSOA via a free space setup, as shown in Fig. 1. The beamsplitters allow monitoring of the input and output simultaneously. Crossed polarizers are used to control the input intensity, and a mechanical chopper with a gradient transparency mask modulates the input light. The gradient mask creates a triangular waveform, simulating a distorted signal. A commercially available (Emcore model 8085-1100) vertical cavity surface emitting laser (VCSEL) operating at 850nm is used as the amplifier by biasing the device below threshold. The output light is detected with a silicon photodiode.
Figure 1: Experimental setup

The static input/output curve is shown in Fig. 2. The optical threshold power required is about 1 µW. The extinction ratio is taken as the ratio of the output power on either side of the maximum slope region (dashed lines in Fig. 2, and is greater than 6:1. Further details of the optical transfer of the device may be found in [7]. The modulated input and output are shown in Fig. 3. The input peaks vary in amplitude because the plastic transparency mask partially polarized the light, completely extinguishing one of the five transmission windows. (Fig. 1,3)

![VCSOA Optical output vs. input. Dashed lines denote on and off-state power levels.](image)

Fig. 2: VCSOA Optical output vs. input. Dashed lines denote on and off-state power levels.

The VCSOA provides >10dB gain as shown in Fig. 3a, while suppressing those peaks and noise below the threshold, shown as a dashed line in Fig. 3b. Both waveforms are plotted on a unity normalized scale in Fig. 3b, to show how the VCSOA reshapes the signal. The inset of Fig. 3b is a magnified plot of the peak signal on a linear scale, showing how a pulse is reshaped by the VCOSA. Using the ratio of peak 3 to peak 5, the extinction ratio is improved from 1.7 (2.3dB) to 4.7 (6.7dB). If one discounts the large peaks below the threshold (2 and 5), the original extinction ratio, measured between peak 3 and 1, is 10dB. After amplification, the ratio is increased to 16.5dB. Also, note that this improvement in the extinction ratio is possible despite the spontaneous emission added to the signal, which is evident in the increased background in Fig. 3a. Finally, the inset of Fig. 3b shows how the individual pulses are reshaped. The input signal is roughly triangular, and is clearly made more square-like after amplification.
Fig. 3: Log-linear plot of optical input and output. Dotted lines are input. Solid lines are output. a) I/O are plotted to same scale, to show amplification. b) I/O is normalized to unity, to show extinction ratio improvement and pulse reshaping. Inset is linear plot of peak 4. Dashed line shows threshold level, peaks are numbered sequentially.

These results show that the differential gain of the VCSOA can be used to perform 2R regeneration of optical signals. The temporal response of this non-linearity is still uncertain. It has been predicted that the response time of dispersive optical bistability should be limited by the carrier recombination lifetime in the SOA [9], and has been experimentally measured to be about >500ps in Fabry-Perot (FP) SOAs[10]. The VCSOA may have some advantage here over FP SOAs because of the small active volume and the use of a quantum well gain medium. In preliminary experiments with VCSOAs, an optical response time of about 100ps has been observed. Our measurements of the high-speed response will be presented at the conference.

The VCSOA as a standalone device cannot match the performance of the interferometric systems mentioned earlier. Those systems achieve better contrast ratio (20dB[3]), speed response (>80Gb/s [1]), and wider wavelength ranges(20nm [2]). However, the improved performance comes at the cost of added complexity, size and expense. The VCSOA is far simpler and much more compact. Additionally, VCSOAs can, in theory, be easily manufactured in dense, 2-D arrays for highly parallel operation, which is difficult or impossible to implement with interferometric systems. It should be noted that many all-optical regeneration systems use non-linear SOAs as the active element [1]. It may be possible to replace the edge-emitting SOAs used in those systems with VCSOAs and achieve performance gains because of the lower threshold power and better coupling efficiency[7,8]. Thus, the authors do not envision that VCSOAs would replace these types of regenerators, but rather complement and improve them.

3. Conclusion

In summary, all-optical 2R logic regeneration has been demonstrated using a non-linear VCSOA. The VCSOA has a optical threshold of 1uW, optical gain of >10dB and >6:1 extinction ratio. A 6dB improvement in extinction ratio
and pulse reshaping are achieved. Compared to other all-optical regeneration schemes, the VCSOA is a simple and inexpensive device and thus may also allow implementation of optical regeneration in systems where it would otherwise be unfeasible due to cost or complexity.

7. References


