

# Dynamic optoelectronic read/write memory

R. N. Nottenburg, A. F. J. Levi, T. Tanbun-Ek, and R. A. Logan  
 AT&T Bell Laboratories, Murray Hill, New Jersey 07974

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We have used multielectrode laser diodes to demonstrate a dynamic digital optoelectronic memory with read and write capability. Pulses 5 ns wide are recirculated in the system every 50 ns. Bits may be modified by applying positive or negative voltage control pulses to an intracavity absorber in the device.

Pulse shaping and memory are important functions in digital communication and computation systems. Pulse shaping is required so that digital signals can propagate through a circuit without errors and memory allows a straightforward means by which to manipulate data. In telecommunication applications pulse shaping is needed following the amplification of weak signals in background noise and is normally achieved by an electronic decision circuit consisting of a comparator which performs the function of threshold detection. In switching systems pulse shaping, memory, and multiplexing is used to store and modify data streams. To date, these functions are performed by transistor circuits. However, at high data rates it is useful not only to connect complex digital electronic circuits but also to emulate some of their functionality using optoelectronic devices.<sup>1</sup> For example, a semiconductor laser which can be driven by emitter-coupled logic gates eliminates the need for laser drivers. Thus, there is a need to develop new functional devices which do not necessarily contain transistors and which are compatible with large scale digital electronics.

It is unlikely that photonics will supplant pure electronics. However, it is worth mentioning that much effort in optoelectronics has centered on the monolithic integration of conventional transistors and photonic devices.<sup>2</sup> Unfortunately, this has resulted in a compromise of individual device design which ultimately results in a degradation of overall performance. In contrast, a hybrid circuit allows optoelectronic structures (not necessarily containing transistors) and pure electronic components to be optimized independently of each other (e.g., Si electronics and III-V optoelectronics).

In this letter we report progress in developing optoelectronic devices which are compatible with digital electronics. Previously, it was shown that a small saturable absorber monolithically integrated into a semiconductor laser diode cavity<sup>3,4</sup> can be used to switch large amounts of lasing light power with a small change in electrical input power.<sup>5</sup> In addition we have shown that multielectrode lasers may be used to perform time division demultiplexing (logical AND operation) at Gbit s<sup>-1</sup> rates.<sup>6</sup> Here we report an optoelectronic dynamic digital memory with bit manipulation.

Buried-heterostructure graded-index separate confinement heterostructure laser diodes with four InGaAs quantum wells (4QWs) were grown using atmospheric pressure metalorganic vapor phase epitaxy (MOVPE) with a layer structure described previously.<sup>6</sup> Substrates are <100> oriented InP, growth temperature is 625 °C, and arsine, phosphine, trimethylgallium, trimethylindium in a hydrogen carrier gas

are the source materials. The *n*-type (S) and *p*-type (Zn) impurities are introduced using H<sub>2</sub>S and diethylzinc, respectively. Following crystal growth, BH lasers are formed by first stripe mesa etching, then using a selective etch to reduce the width of the active region to around 2 μm and finally regrowing with semi-insulating Fe-InP using MOVPE.<sup>7</sup> Electrical contact to the *n*<sup>+</sup> and *p*<sup>+</sup> layers is realized using standard etching and metallization techniques. Figure 1(a)

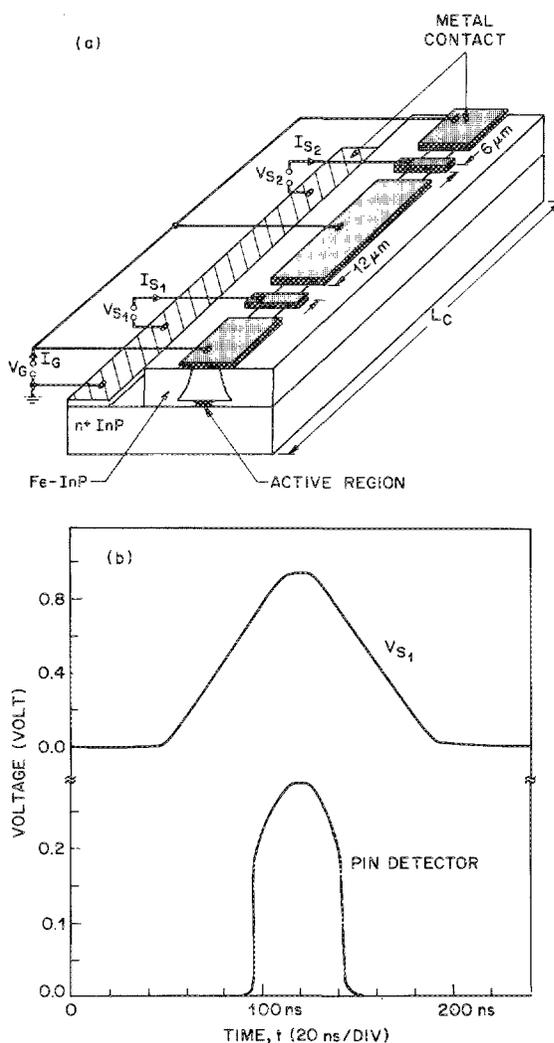


FIG. 1. (a) Schematic diagram of a BH GRINSCH 4QW laser diode with a cavity length  $L_C$  and two absorbers  $S_1$  and  $S_2$ . The current into the long gain section is  $I_G$ , the absorber voltages and currents are  $V_{S_1}$  ( $V_{S_2}$ ) and  $I_{S_1}$  ( $I_{S_2}$ ), respectively. (b) Upper trace is voltage applied to  $S_1$  as a function of time. Lower trace is voltage detected by a *p-i-n* photodiode used to monitor light output from the laser.  $I_G = 40$  mA.

shows a schematic diagram of the geometry used. The gap between the  $p^+$  metal stripes is  $12\ \mu\text{m}$  and the length of the absorber sections  $S_1$  and  $S_2$  is  $6\ \mu\text{m}$ . The long metal stripes are electrically connected and defined as the gain section. In the completed structure the isolation resistance between the segments and the gain section is greater than  $1\ \text{k}\Omega$ . Uncoated laser mirrors are formed by cleaving, cavity length is  $L_C \approx 500\ \mu\text{m}$ , and lasing wavelength is  $\lambda = 1.5\ \mu\text{m}$ .

Figure 1(b) shows the lasing light output (lower curve) detected by an InGaAs pin photodiode in response to a triangular voltage pulse applied to  $S_1$  (upper curve). In this experiment  $S_2$  is electrically connected to the gain sections. As may be seen, the triangular electrical waveform is converted into a narrow optical pulse. The pulse width is determined by the saturation characteristics of the absorber  $S_1$  as discussed in Ref. 6. This demonstrates threshold detection which, as described above, is desirable in a digital circuit. Logical OR is implemented when the gain section is biased such that lasing digitally switches on with either  $S_1$  or  $S_2$  having a voltage greater than  $0.2\ \text{V}$ . As shown in Fig. 2, a dynamic optoelectronic memory may be accomplished by feeding back the amplified electrical response from the detected lasing output into  $S_2$ . In this way arbitrary data may be read in at  $S_1$  and recirculated via  $S_2$ . Experimental results illustrating this function are shown in Fig. 3 where a 1010 data stream is written (upper curve) and stored (lower curve). In this example the pulses are  $5\ \text{ns}$  wide corresponding to a  $200\ \text{Mbit s}^{-1}$  rate and the memory cycle time is  $\Delta t = 50\ \text{ns}$ . The cycle time is primarily controlled by an electrical delay line. However, this delay line may be replaced by an appropriate length of optic fiber.

Having written data into the memory within a time  $\Delta t$  it

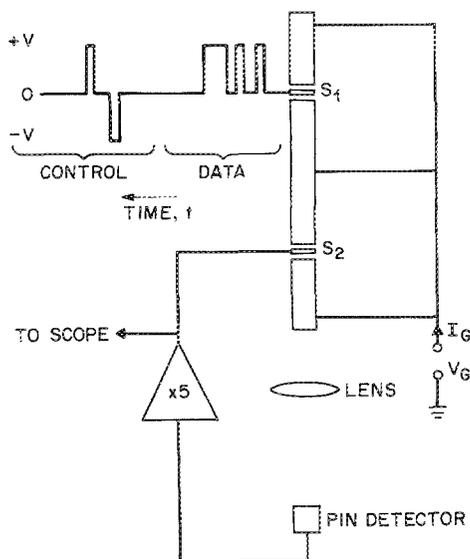


FIG. 2. Schematic diagram of the experimental arrangement to demonstrate memory and bit add/drop. The initial electrical data stream is applied to  $S_1$  and the resulting optical output from the laser is detected using a pin photodiode. Data are recirculated every  $50\ \text{ns}$  in the device by applying the amplified voltage output from the pin to  $S_2$ . Add/drop is achieved after reading in the initial data shown by applying positive or negative control voltage to  $S_1$ .

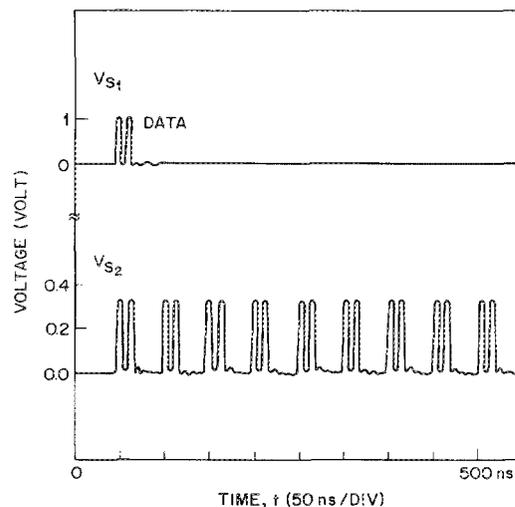


FIG. 3. Experimental results demonstrating an optoelectronic memory using the arrangement shown in Fig. 2.  $I_G = 80\ \text{mA}$ .

is possible to manipulate the stored data by applying control signals to  $S_1$ . As shown schematically in Fig. 2, a negative voltage pulse may be used to quench lasing and therefore remove (or drop) one bit of stored information. Addition of one bit to the stored memory is achieved by sending a positive voltage pulse to  $S_1$  which causes the laser to switch on.

Experimental results demonstrating this add/drop capability are shown in Fig. 4. A [1010000000] 10 bit word is written to  $S_1$  at a  $200\ \text{Mbit s}^{-1}$  rate. These data are stored and recycles once in the memory (lower curve in the figure). A negative voltage control pulse at  $S_1$  is then used to remove the first bit in the word and the modified [0010000000] data again recycles in the memory. Later a positive voltage control pulse at  $S_1$  adds a bit in the word and the new word [0010000010] recycles in the memory.

In conclusion, we have shown that the nonlinear output characteristics of lasers with saturable intracavity absorbers

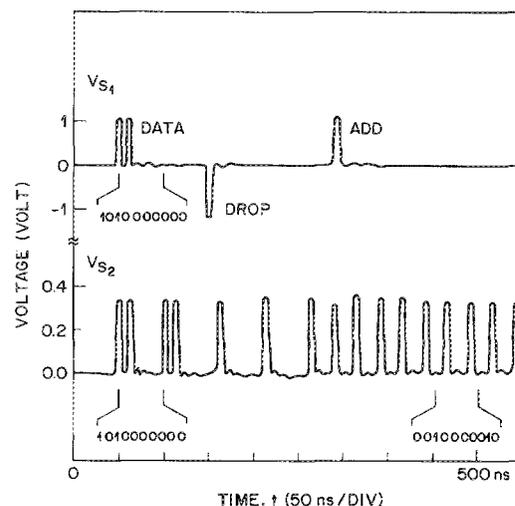


FIG. 4. Experimental results demonstrating an optoelectronic memory with bit add/drop capability using the arrangement shown in Fig. 2.  $I_G = 90\ \text{mA}$ .

are compatible with digital signal processing because they may be used for threshold detection and pulse shaping. We have exploited this fact and used a multielectrode laser to form a dynamic optoelectronic memory with read and write capability. This type of optoelectronic data manipulation may be useful in ultrafast digital systems.

<sup>1</sup>*Optical Switching in Low-Dimensional Systems*, NATO ASI Series, Vol. B194, edited by H. Haug and L. Banyai (Plenum, New York, 1989).

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<sup>3</sup>E. O. Göbel, R. Höger, J. Kuhl, H. J. Polland, and K. Ploog, *Appl. Phys. Lett.* **47**, 781 (1985).

<sup>4</sup>Y. Arakawa, A. Larson, J. Paslaski, and A. Yariv, *Appl. Phys. Lett.* **48**, 561 (1986).

<sup>5</sup>K. Berthold, A. F. J. Levi, T. Tanbun-Ek, R. A. Logan, and S. N. G. Chu, *Appl. Phys. Lett.* **55**, 1940 (1989).

<sup>6</sup>A. F. J. Levi, R. N. Nottenburg, R. A. Nordin, T. Tanbun-Ek, and R. A. Logan, *Appl. Phys. Lett.* **56**, 1095 (1990).

<sup>7</sup>T. Tanbun-Ek, R. A. Logan, and J. P. Van der Ziel, *Electron. Lett.* **24**, 1483 (1988).