Extended Abstracts of the 21st Conference on Solid State Devices and Materials, Tokyo, 1989, pp. 321-324

D-6-2

New Reset Method for Optical Bistable Laser Diodes

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We propose a new reset for a bistable laser diode for high speed switching. This method keeps the change of the carrier density in the active layer extremely small during reset. The diode has, at low incident optical power, very fast switching. A memory operation of 1 Gbit/s is obtained with the bistable laser using the new reset method.

1. Introduction

The bistable laser diode (BSLD)[1-4] having optical memory and switching is a key device in optical computing and exchange systems. 512 Mbit/s (four 128 Mbit/s) optical time-switching system has been reported,[2] but faster switching is needed to construct the above systems. A 170-ps switching response has been reported,[3] but as the excess carriers are extracted from the active region by applying a large negative current pulse, carrier density in the active layer varies greatly from the steady state and a longer recovery time (a few nanoseconds) is needed before the carrier density becomes steady. If the next set pulse comes before this recovery time, the BSLD is unstable for turn-on and turn-off.[4] In this letter, we propose a new reset in which the carrier density remains relatively constant. Using this method, we achieved memory operation faster than 1 Gbit/s.

2. Principles

Figure 1 shows the relation between gain and carrier density in the active layer. Gain saturates with increasing carrier density. In case of conventional reset, DC bias is applied to the electrode as indicated by point A in Fig. 1 and kept in the gain region. The large negative current pulse is applied to the electrode for reset. The carriers in the active layer are extracted from the active region to the electrode. Reset is done by decreasing the gain (Δg). As large carrier density in the gain region changes, large optical set power which is proportional to the carrier change is needed or long time interval between reset and set pulse is

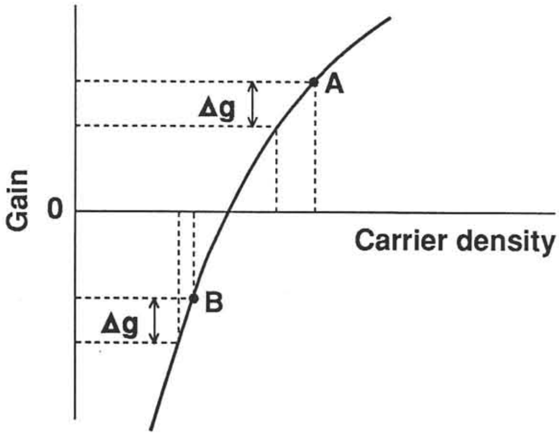


Fig. 1. Dependence of gain and carrier density in the active layer of BSLD. Point (A) is conventional method, (B) is mew method.

needed for stable operation. We propose a new reset method to solve this problem. If the bias is set to the lower carrier density indicated by point B and reset is done by decreasing the gain by the same amount Δg, carrier change of the active layer is to be very small. Then small optical set power and short time interval should be achieved. To do this one of the tandem electrodes is biased near the diffusion potential of the p-n junction and BSLD is reset by applying the negative voltage. Namely this region should act as a loss region and BSLD be reset by increasing the loss of this region.

3. BSLD structure

Figure 2 shows the tandem electrode optical bistable laser diode used in our experiments. The region 1 is 16 μm long, the saturable absorption, 28 μm, and the region 2, 256 μm. The active layer (λ=1.3 μm) is embedded with an Fe-doped semi-insulating (SI) InP current-blocking layer grown by MOVPE.5) The resistivity of the SI-InP is more than 10^8 Ωcm. High resistance between the two electrodes is needed to control each region independently. The resistance between the electrodes is as high as 8 kΩ. The capacitance of the device is less than 3 pF. The devices are bonded to the diamond heat sinks p-side up. A DC bias current is applied to the region 2, and small DC bias voltage near the diffusion potential of the p-n junction is applied to the region 1.

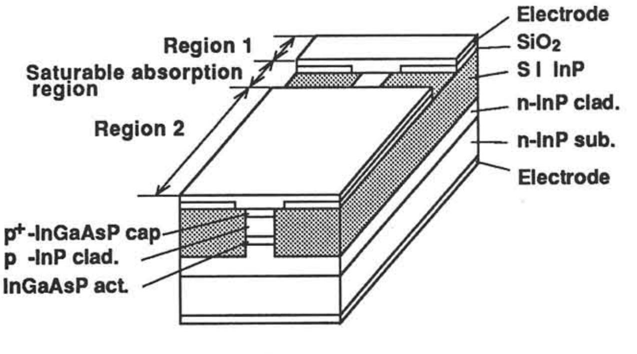


Fig. 2 Structure of BSLD.

4. Experiments

Figure 3 shows the experimental setup. Light power from a DFB laser diode is injected into the BSLD. The intensity of the light input is controlled by the optical attenuator. An InGaAs pin photodiode (bandwidth 10-GHz) is used to measure the dynamic characteristics. To adjust reset and set pulse time interval, two pulse pattern generators are used. The injected optical power is calibrated from the photocurrent of the BSLD, assuming the facet reflectivity to be 0.3 and internal quantum efficiency to be 1.0.6)

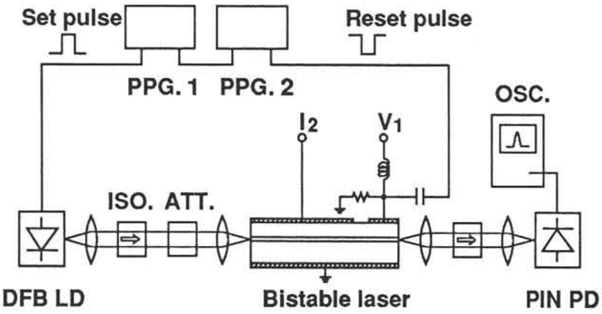


Fig. 3. Experimental set up.

The relation between an applied DC voltage (V_1) and turn-on (I_{on}) and turn-off (I_{off}) currents is shown in Fig. 4. I_{on} and I_{off} increase as V_1 decreases. When the BSLD lases, a negative current is observed through the applied voltage region even though DC bias is applied forward the p-n junction. Therefore it was considered that the applied voltage region acts as a loss region, and the loss increases with decreasing bias voltage. The hysteresis loop narrows with decreasing voltage and vanishes below 0.2 V. It suggests that the nonlinear effect of the saturable absorption region are decreased and is covered by the large loss at region 1.

To know the carrier change during reset, we studied the relation between the time interval between reset and set pulses (t_1) and the minimum power (P_{min}) necessary to set, the

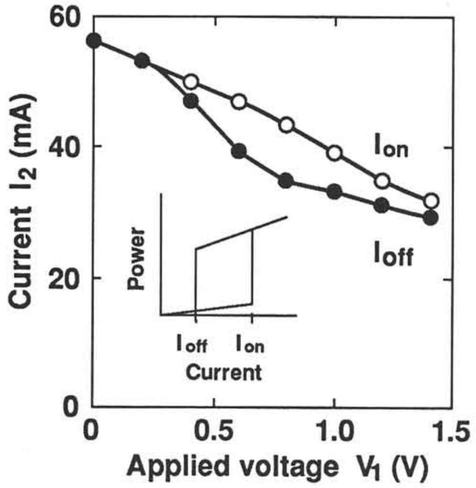


Fig. 4. Relation of applied voltage verses turn-on (I_{on}) and turn-off (I_{off}).

power P_{min} is thought to be proportional to the carrier change due to reset signal as described previously. Figure 5 shows the results for new reset, and conventional reset in which a large current is removed from the electrode. The bias conditions are summarized in Fig. 6. Current bias is set at the center of the hysteresis loops. The width of the reset and set pulses are both 200 ps. In both methods, the minimum set powers become constant at $t_1>3$ ns. This suggests the carrier change caused by reset is fully recovered at $t_1>3$ ns. There is a great difference between new reset and conventional reset at $t_1<3$ ns. In the conventional method P_{min} increases rapidly below 2 ns. We could not make the BSLD lase below $t_1<1$ ns, even if the incident optical power exceeded 500 µW. On the other hand, in case of new reset, set operation is achieved with a small injection power of only 230 µW, even when the time interval becomes short. Figure 7 shows the relation between the minimum optical power for set and the time interval for different bias voltages. The reset pulse (V_R) is -0.3 V. These bias currents are set 0.2 mA below I_{on}. The pulses of set and reset are 200 ps wide. As bias voltage decreases, the minimum optical power for set and the power variation from the steady state decrease. Carrier

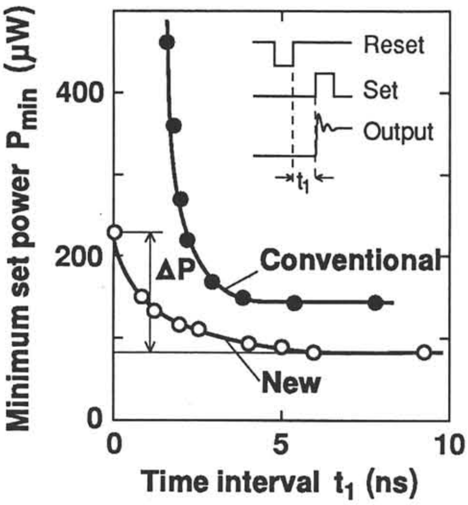
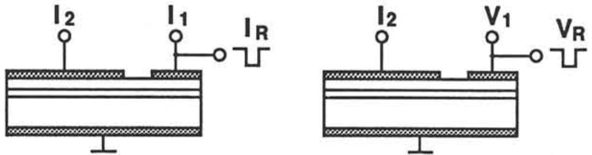


Fig. 5 Dependence of the minimum power necessary to set and time interval between set and reset pulses. Open circle is conventional reset method, and closed circle is new reset method.



I_1 (mA)	I_2 (mA)	I_R (mA)
8.3	30.0	6.5

a) Conventional reset

V_1 (V)	I_2 (mA)	V_R (V)
0.85	40.0	0.7

b) New reset

Fig. 6. Bias conditions of conventional reset (a) and new reset (b).

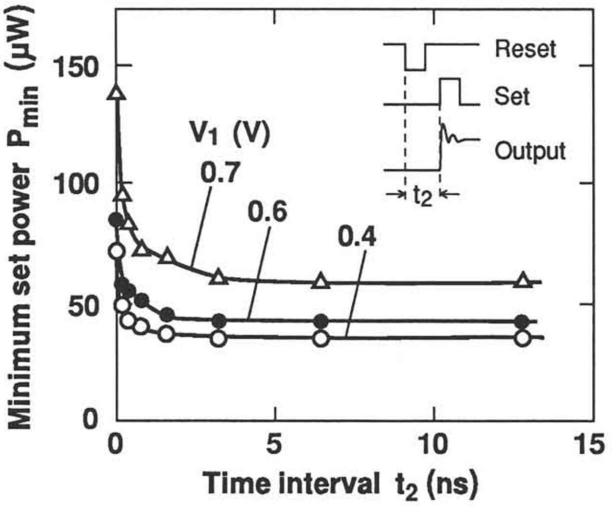


Fig. 7. Time interval dependence of the minimum set power as varying the DC bias voltage.

change by reset is extremely small, about 0.4 V. We expect high speed switching operation at 0.4 V.

Optical memory operation of the BSLD is shown in Fig. 8. The bias current is the center of the hysteresis loop, and bias voltage is 0.4 V. The upper trace is the set pulse (pulse width 120 ps, optical power 86 μW), the middle is reset pulse (200 ps, V_R=-0.5V), and the lower is optical output. The optical output of the BSLD corresponds to the set pulses "1","1","0","1". High speed optical memory operation of 1 Gbit/s is achieved using the new reset method.

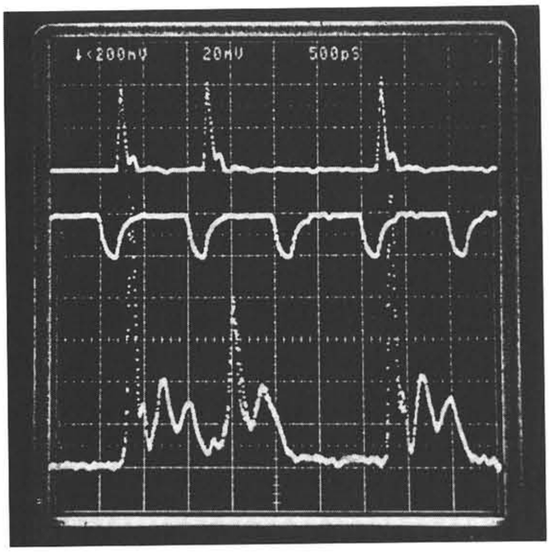


Fig. 8. Memory operation of BSLD. The three traces are set (upper), reset (middle), and output power (lower). Time scale is 500 ps/div.

5. Conclusion

We proposed a new reset of an optical bistable laser for high-speed switching. It was shown that the carrier change during the reset process was extremely small for the new reset. We obtained 1 Gbit/s memory operation with the bistable laser using this reset method.

Acknowledgments

We thank Drs. T. Misugi and T. Sakurai for their continued encouragement and valuable advice. We are also thank Messrs. K. Nakai and K. Kondo for their helpful discussion.

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