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All Optical Flip-Flop Operation of Bistable Laser Diode

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Optical set and reset characteristics of a bistable laser diode(BSLD) are studied. Resonant phenomenon in wavelength dependence of set light intensity are observed. New optical reset method that the BSLD can be reset by the light injection is discorverd. And all optical flip-flop operation of BSLD is demonstrated.

1. Introduction

The bistable laser diode (BSLD) is a key device for optical memory and optical logic device which are needed for constructing optical switching and optical computing systems. For optical memory, the BSLD is usually set by an optical pulse and reset by an electrical pulse [1]. But the electrical reset pulse causes electrical cross talk which limits the degree of integration and switching speed. Therefore, it is desirable to control BSLD by only optical signals.

In this letter, we study optical set and reset phenomena. We measured wavelength dependence of threshold set light intensity in detail and report new phenomenon that injection light resets the BSLD. We also demonstrate all optical flip-flop operation by set and reset light pulses.

2. Structure of BSLD

Figure 1 shows the structure of the BSLD we used. It has tandem electrodes to control hysterisis. The length of gain region 1 is 70 μm, gain region 2 is 190 μm, and the saturable absorption region is 40 μm. The active region is embedded with a semi-insulating(SI) InP layer grown by MOCVD [2]. The resistivity of the SI InP layer is more than 10^8 Ωcm. This BH laser, which uses an SI layer, is superior to conventional p-n junction BH laser, because for the BSLD of tandem electrodes, it is important to have high resistance between the two electrodes to control the injection currents independently. The contact layer of the saturable absorption region is removed by chemical etching to increase resistance between the two electrodes. The resistance between the two electrodes is about 10 kΩ.

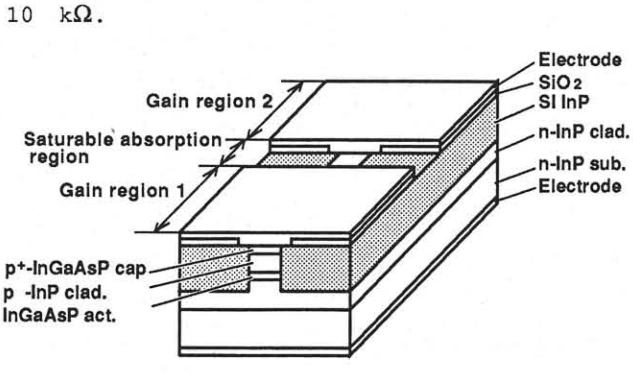

Figure 1. Structure of BSLD.

3. Experimental condition

Figure 2 shows an example of current/light output characteristics. I_1 and I_2 are the currents in gain region 1 and 2. When I_2 = 38.0 mA, the threshold turn-on current I_{1on} = 8.3 mA and turn-off current I_{1off} = 6.0 mA. In the hysterisis region, peak wavelength in the lasing and EL state are about 1.302 μm and 1.307 μm. A DFB laser is used as an injected light source. The wavelength of the injected light is controlled by heat-sink temperature. The intensity of injected light is calculated from the photo-current of the BSLD, assuming the facet reflectivity to be 0.3 and internal quantum efficiency to be 1.0.

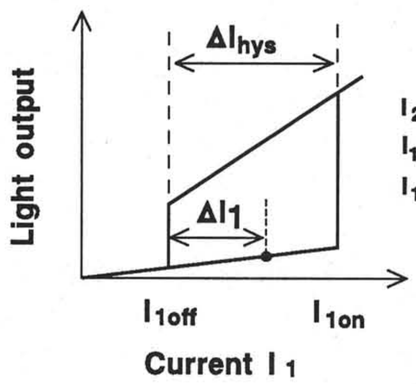

Figure 2. Current/light output characteristic.

Current bias, I_1, was set at 7.3 mA (I_{1on}-I_1=1.0 mA). Figure 3 shows the experimental wavelength dependence of threshold set light intensity. The arrows in the figure point to the resonant wavelengths in the EL state of the BSLD. This shows that threshold set light intensity strongly depends on it's wavelength and it has minimums around the resonant wavelength of the EL state. Minimum and maximum intensities are about 1 μW and 150 μW.

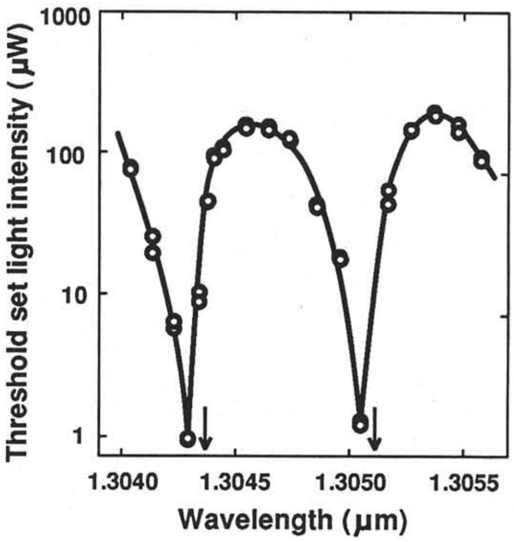

Figure 3. Wavelength dependence of threshold set light intensity.

4. Optical set characteristics

It has been reported that the threshold light intensity to set BSLD little depends on it's wavelength if the wavelength of the set light is between the peak wavelengths in lasing state and EL state (about 100 Å wide) (1). The BSLD, however, has a cavity with gain regions. Therefore, the wavelength dependence of threshold set light intensity should depend on the characteristic of F.P. cavity when the set light is colinearly injected into the BSLD. We examined this dependence in detail.

5. Optical reset characteristics

Optically resetting a BSLD has not been tried until now. We found that a BSLD can be reset by injecting long wavelength light.

Figure 4 shows spectral changes in BSLD by longer wavelength light injection. Bias current I_1 is set at 6.9 mA(I_1-I_{1off}=0.9 mA). Lasing wavelength of the BSLD and the injection light wavelength were 1.3023 and 1.3154 μm. a) First, we set the BSLD in the lasing state. b) Lasing continued when the injection light intensity was 40 μW. c) When injection light intensity reached 200 μW, the BSLD stopped lasing, and only the injection light was observed. d) After injection light decreased to 0 μW, the BSLD remained off (EL state).

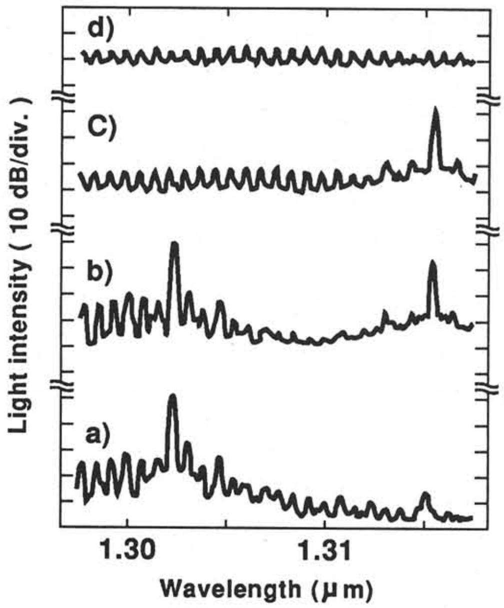

Figure 4. Spectral change in BSLD by light injection of intensity a) 0, b) 40, c) 200, and d) 0 μW.

We measured the wavelength dependence of the threshold light intensity to reset the BSLD (figure 5). Injection light wavelength was changed from 1.315 μm to 1.316 μm. Maximum intensity of injection light was about 700 μW. Bias current I_1 is set at 6.1, 6.5, 6.9 mA ($\Delta I_1 = I_1 - I_{1off} = 0.1$, 0.5, 0.9 mA). The arrow shows the resonant wavelength of the BSLD not in EL state but in the lasing state. In the BSLD, they are different, because the carrier density of the active layer changes between the two states. The closer the injection light wavelength is to the resonant wavelength of the lasing state, the lower the threshold reset light intensity. We also found that the threshold reset light intensity decreases with decreasing bias current of BSLD.

The mechanism of optical reset phenomenon is considered that injected light decreases the carrier densities of the gain regions by amplifying the injected light by stimulated emission, therefore the gain of lasing mode also decreases, and the BSLD stops lasing. However, light injection with a wavelength close to the lasing peak wavelength, can not reset the BSLD, but the longer wavelength light injection can reset BSLD. This is because that both the longer wavelength light and the light whose wavelength is close to lasing peak, decrease the carrier density of two gain regions, however, the former is less absorbed by the saturable absorption region than the latter, therefore as a whole the former more decrease the net gain of lasing mode than the latter.

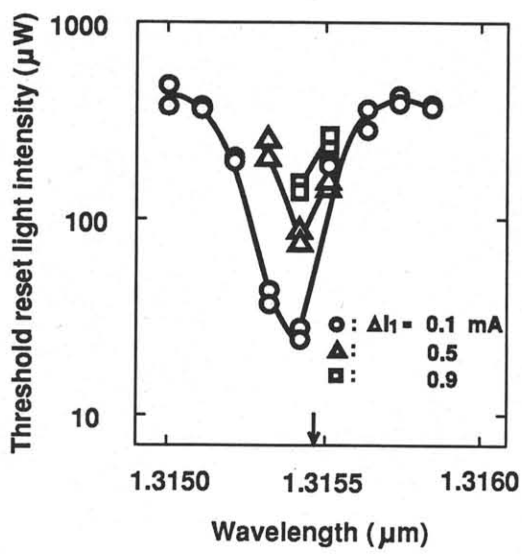

Figure 5. Wavelength dependence of threshold reset light intensity. The arrow points to the resonant wavelength of BSLD.

6. All optical flip-flop operation

Using the phenomena above mentioned, all optical flip-flop operation of BSLD have been demonstrated. Figure 6 shows the experimental setup. The set and reset light was coupled by a fiber coupler then injected into the BSLD colinearly. The light output of BSLD is detected by a PIN photodiode. Wavelength of set and reset light are 1.3044 and 1.3154 μm, and light intensities are 30 and 90 μW. Pulse widths are about 20 ns. The result is shown in figure 7. Output light of the BSLD corresponds to the injection set light signal "1","1","0".

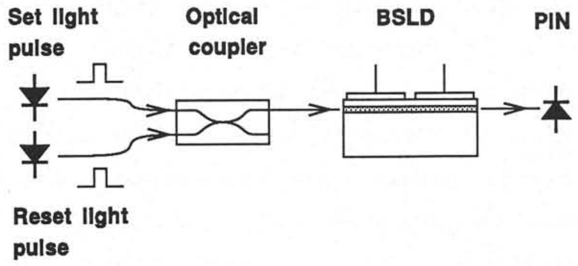

Figure 6. Experimental setup.

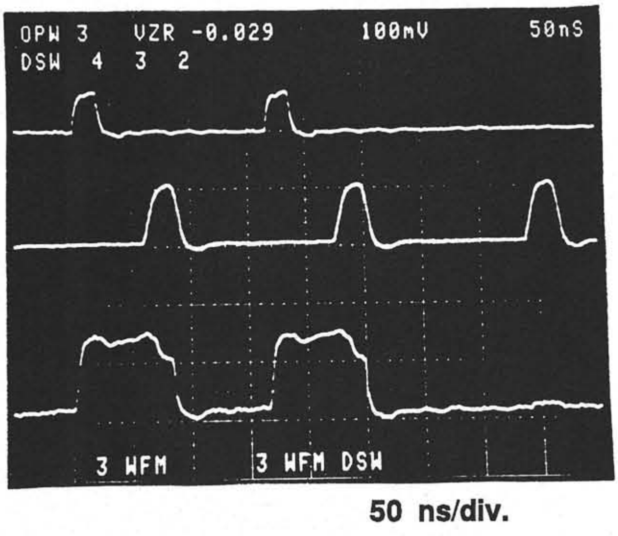

Figure 7. Optical flip-flop operation of BSLD.The three traces are set light (upper), reset light (middle), and output light of BSLD(lower).

7. Conclusion

We measured the wavelength dependence of the threshold set light intensity and found that it strongly depends on the relation between the set light wavelength and the wavelength of the BSLD in the EL state. We also discovered a new optical reset method in BSLD, and have operated an all optical flip-flop operation.

Acknowledgments

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Reference

(1) S. Suzuki, T. Terakado, K. Komatsu, K. Nagashima, A. Suzuki, and M. Kondo, "An Experiment on High-Speed Optical Time-Division Switching," IEEE J. Lightwave Technol., **LT-4**, 894 (1986).

(2) K. Wakao, K. Nakai, T. Sanada, M. Kuno, T. Odagawa, and S. Yamakoshi , "InGaAsP/InP Planer Buried Heterostructure Lasers with Semi-Insulating InP Current Blocking Layers Grown by MOCVD," IEEE J. Quantum Electron., **QE-23**, 943 (1987).