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Dynamic Set and Reset Operations of a Side-Light-Injection MQW Bistable Laser

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Dynamic set and reset operations of a side-light-injection MQW bistable laser are achieved using absorption saturation and gain quenching. This device consists of one main bistable laser and two waveguides perpendicular to the main laser. The voltages applied to the gain quenching and saturable absorption region are +1.00 and +0.29 V, respectively. As the input light intensity increases, the turn-on and turn-off times decrease. The turn-on time is 200 ps when the input light peak intensity is 1 mW and the turn-off time is 2 ns when the input light peak intensity is 200 mW.

1. Introduction

A bistable laser that can be set and reset using only input light is a promising device for achieving an optical logic device and realizing optical switching and computing systems. The static set and reset operations of a side-light-injection MQW bistable laser have already been reported.[1)] This device consists of one main laser for bistable operation and two waveguides perpendicular to the main laser for propagating the input signals into the intersection. Set and reset operation was obtained with memory and a 10:1 contrast ratio. This is superior to the performance of standard side-light-injection-type lasers.[2,3)] This side-light-injection structure might be used for improving the sensitivity to the input wavelength and for isolating the input and output signals.[4,5)] Another optical set and reset bistable laser candidate has been reported,[6)] but the input light dependence of the switching time was not mentioned. This letter demonstrates the set and reset operation of a side-light-injection MQW bistable laser and the input light intensity dependence of the switching time.

2. Device Structure

Figure 1 shows a scanning electron microscope (SEM) image of the device. The SCH-MQW active region consists of six-period InGaAs (L_w = 90 Å)/InAlAs (L_B = 30 Å) sandwiched between an InGaAsP (λ_g = 1.2 μm) optical guiding layer, which was grown by gas-source molecular beam epitaxy. The MQW structure was introduced to achieve high-speed performance and to improve controllability of the hysteresis characteristics by using the quantum confined Stark effect.[7)] The InAlAs barrier layers are expected to improve the characteristics of the absorption saturation because their conduction band discontinuity is large enough to enhance the effects of the two-dimensional exciton.[8)] These structures also have the advantage of suppressing hole pile up due to small valence band discontinuity. The ridge structures of this device are formed by chemical etching. The polyimide is spin-coated to obtain a planar surface and to

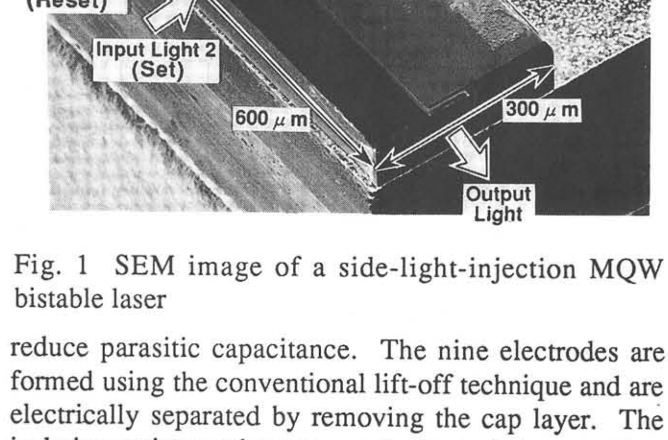

Fig. 1 SEM image of a side-light-injection MQW bistable laser

reduce parasitic capacitance. The nine electrodes are formed using the conventional lift-off technique and are electrically separated by removing the cap layer. The isolation resistance between each electrode is more than 1 kΩ. All four facets are cleaved and have no anti-reflection coating. The cavity of the main laser is 600 μm long

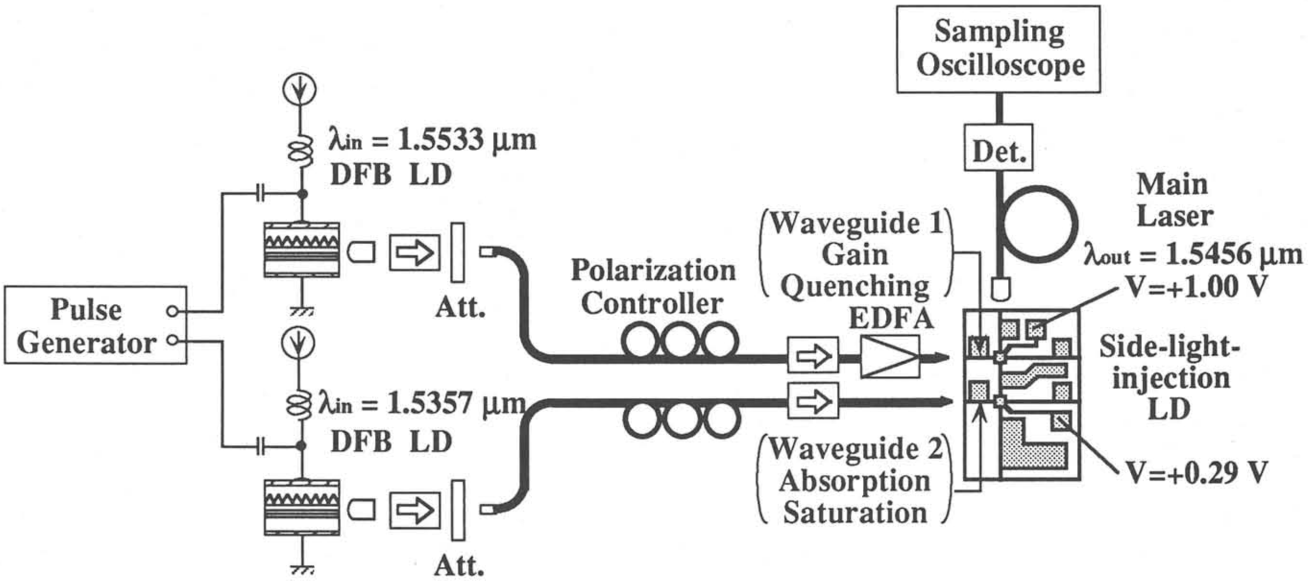

Fig. 2 Experimental set-up for switching ON/OFF operations of a side-light-injection MQW bistable laser

and the ridge is 3 μm wide. The cavity of the main laser is formed in the <011> direction and has two 6 μm × 6 μm intersections in the middle of the cavity. The two gain waveguides have a cavity length of 300 μm and a 6 μm ridge width. Since the configuration of the two intersections is the same, the difference between the gain quenching region and the saturable absorption region is determined by the applied voltages.

3. Set and Reset Operations

The experimental set-up is shown in Fig. 2. In this experiment, the light emitted from one DFB laser (λ_{in} = 1.5357 μm) was injected directly into the saturable absorption region. Light emitted from the other DFB laser (λ_{in} = 1.5533 μm) was amplified by an Er-doped fiber amplifier and injected into the gain quenching region. The wavelength of the amplified light was selected so as to be longer than that of the main bistable laser (λ_{out} = 1.5456 μm). This input light with the longer wavelength produces efficient gain quenching. Both wavelengths were adjusted to one of the Fabry-Perot resonance peaks of the electroluminescence spectra from each waveguide in order to lower the switching threshold power. The voltage applied to the gain quenching region was +1.00 V and a few carriers were injected so that gain quenching occurred when the input light was injected. The voltage applied to the saturable absorption region was +0.29 V and the input light caused absorption saturation. The injection currents into both waveguide regions were 60.0 mA in order to amplify the input signals. Under these conditions, the device had 1 mA wide hysteresis characteristics. The bias current of the main laser was 65.5 mA, which was 0.6 mA above the electrical turn-off current.

Figure 3 illustrates the set and reset operations of the side-light-injection MQW bistable laser. The device uses only injected light to perform set and reset opera-

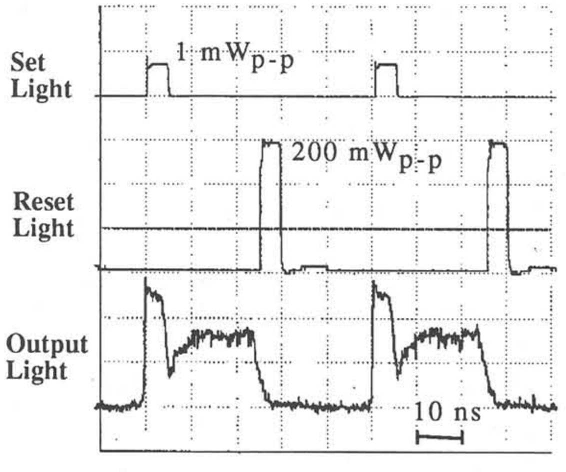

Fig. 3 Switching ON/OFF operations of a side-light-injection MQW bistable laser

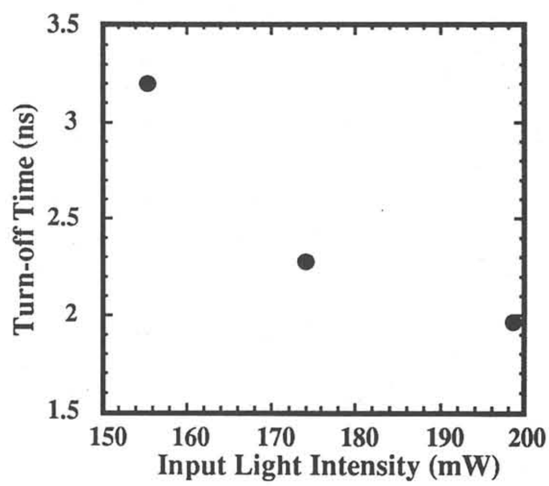

Fig. 4 Turn-off time dependence on input light intensity

tions. The widths of both the set and reset light is 5 ns. The spikes seen at the onset of the output light are not the amplified input signal but the lasing light from the main bistable laser itself. The change of carrier density in the laser cavity is attributed to these spikes. The turn-off time decreased gradually as the input light intensity increased as shown in Fig. 4. The turn-off time was less than 2 ns when the input light peak intensity was 200 mW. The turn-off time is limited mainly by the input light intensity because the threshold switching power is rather high.

Figure 5 illustrates the calculated results of the turn-off time by solving the modified rate equation for a two-segmented laser.[9] Input light intensity is normalized by the threshold switching power in the static state. For the calculation, four equations were used that relate to the change of the carrier density in the gain region of

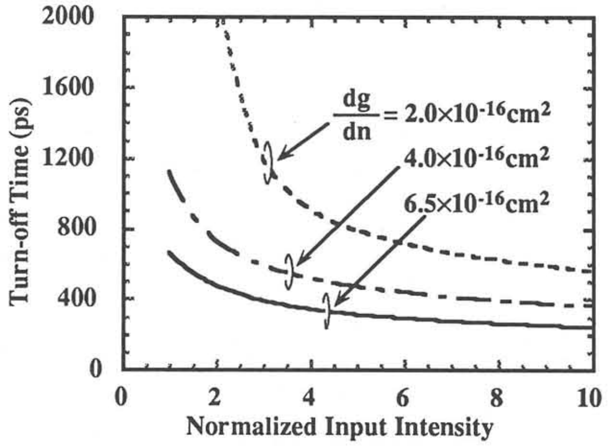

Fig. 5 The dependence of calculated turn-off time on normalized input light intensity

the main bistable laser, the gain quenching region, the saturable absorption region and the photon density in the cavity. The differential gain coefficient of the gain region was varied as a parameter. The values used for calculation, 6.5×10^{-16}, 4.0×10^{-16} and 2.0×10^{-16} cm^2, almost correspond to those of InGaAs/InAlAs,[10] InGaAs/InGaAsP [11] and bulk structures.[11] In these three sets of calculations, the ratio of the differential gain coefficient in the gain quenching region to that of the gain region was chosen to be equal. The differential gain coefficient in the saturable absorption region was selected so that the hysteresis width revealed in the light output versus current characteristics was almost the same between the three structures. As the differential gain coefficient increased, the threshold switching power decreased and the turn-off time was also reduced. These results imply the advantage of the InGaAs/InAlAs MQW structure for improving the performance of the side-light-injection MQW bistable laser. As reported,[12] a structure with a large number of quantum wells is also superior because of the enhancement of the differential gain coefficient. Optimization of the MQW structure, as well as improvement of gain in the waveguide region, are important for achieving a sub-nanosecond switching time.

In addition, the turn-on time also decreased as the input light intensity increased, which agrees with results reported elsewhere.[5] The turn-on time was about 200 ps when the input light peak intensity was 1 mW. Reducing the threshold switching power encourages cascade combinations and the construction of all-optical logic devices.

4. Conclusion

In conclusion, both set and reset operation have been achieved by injection light. High-intensity input light reduces both turn-on and turn-off time. Optimization of the MQW structure and enhancement of gain in the waveguide region could improve device characteristics.

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