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Invited

Laser-Based Devices for Photonic Switching and Computing

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A bistable laser diode with saturable absorber has three states: EL, lasing, and quenching states, which are controlled in sequence by light injection. Using these phenomena, a wavelength converter, optical inverter, optical exclusive OR, and other variety of optical logic functions are realized in the spectrally resolved light output from a single longitudinal-mode bistable laser diode.

1. INTRODUCTION

With the great success of optical transmission systems in the last decade, there has been much interest in photonic switching and computing. Optical functional or switching devices have the key to opening a door to such advanced systems. Among various types of optical functional devices, bistable optical devices have received increasing attention because of their promissing applications for optical memories and optical logic gates. Especially, laser-based one would be a very useful and important device, because of its large optical gain, high on/off ratio, low optical switching power, and large fan-out.

Recently we developed a single longitudinal-mode bistable laser diode with wavelength tuning capability[1], and realized new optical functions such as wavelength converter[1,2], optical inverter(or optical transistor)[2,3], and exclusive OR function[4], as well as optical flip-flop operation[5].

In this paper, we discuss the principle and characteristics of the wavelength converter, and demonstrate optical inverter, and exclusive OR operations by using the spectrally resolved output from the single-mode bistable laser diode.

2. WAVELENGTH CONVERTER

A bistable laser diode with a saturable absorbing region shows a hysteresis characteristic.If the bias currents are set just below the turn-off threshold, the device can lase only when the input light is injected. In this case, input light excites the saturable absorber to make the device lase, and a lasing wavelength is determined by the cavity modes which are independent of the wavelength of input light. Therefore, the bistable laser itself is essentially a wavelength converter. Monolithically integrating the wavelength-tuning region with the bistable laser structure produces a tunable wavelength conversion laser. There are two ways to make the wavelength-tuning, one is multielectrodes DFB structure, the other is DBR structure with phase shifter section. Fig. 1 is a schematic structure of the tunable wavelength conversion laser we fabricated. It has a tandem-electrode structure, consisting of four sections: two gain sections, a phase shifter section and a DBR section. The isolation region between the two gain sections acts as a saturable absorber. The lasing wavelength is tuned by current injection into the phase shifter and the DBR sections.

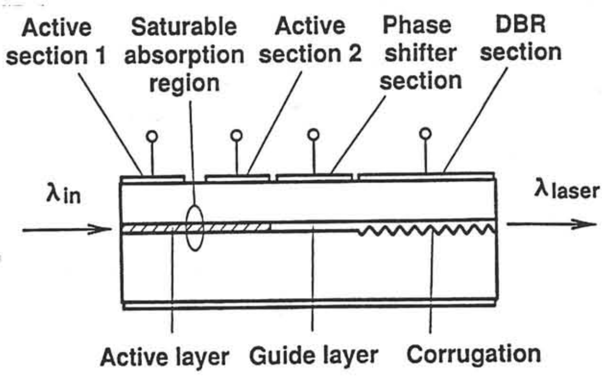

Fig. 1 Schematic cross-section of tunable wavelength conversion laser.

Fig. 2 shows the spectra change of the wavelength converter. Increasing current in the phase shifter and the DBR make the output wavelength short. Single-mode lasing was maintained within a 4.5 nm tuning range. High speed operation at 1 Gb/s has been obtained with extremely low input power of 6 μW[6]. This device is very promising for constructing the new optical systems which utilize the wavelength and time division multiplexing technique.

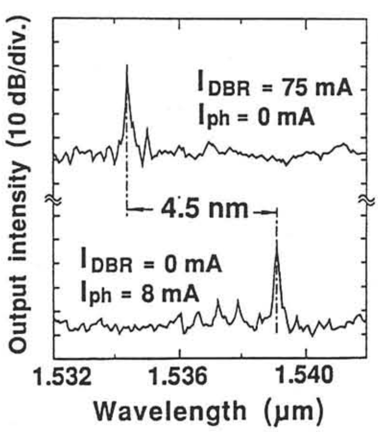

Fig. 2 Lasing spectra change of wavelength conversion laser.

3. OPTICAL INVERTER

Optical inversion output is achieved by utilizing the gain-quenching induced by light injection. In this case, the bias current is set above the turn-on threshold. Since carriers in the gain region are consumed to amplify the injected light input, the spectrally resolved lasing output decreases with gain quenching. Fig. 3 demonstrates the optical inversion operation. Each plot shows the spectrally resolved lasing power and amplified input light. Only 6 μW injection light suppressed the lasing power by adjusting the input wavelength to the side-mode wavelength of the device.

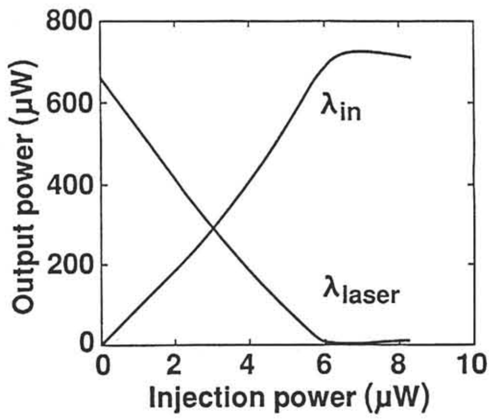

Fig. 3 Optical inversion characteristics.

This device acts as an optical transistor with the optical gain of 20 dB. Lasing output is controlled by not only the input power but also the input wavelength. Furthermore, it should be noted that complementary outputs are simultaneously obtained by separating the wavelength of the output light. In dynamic operation of inverter, high speed inversion with the rise and fall time below 500 ps was obtained[3].

4. EXCLUSIVE OR

An exclusive OR(XOR) is a very important function to construct the logic circuits such as half- or full-adder. For XOR gate, the bias current is set below the turn-off threshold. By increasing the light input(λ_i), the device starts lasing at the wavelength λ_o. A further increase in the optical injection causes gain-quenching, then stops lasing. And only the amplified input is obtained. Fig. 4 shows the experimental result. A and B are input spectra, and L_{lasing} and L_{amp} are output spectra.

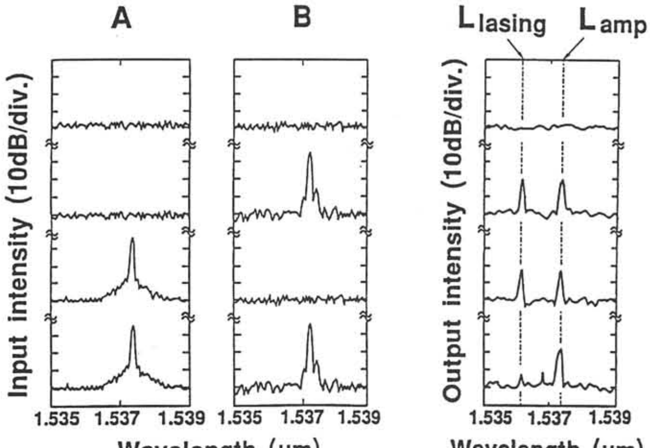

Fig. 4 Optical XOR experimental results.

When either of the two inputs was at the "1" level, the lasing output was at the "1" level. When both of the two inputs were at the "0" or "1" level, the lasing output was at the "0" level. Thus, an optical XOR function was realized by filtering out all but the lasing wavelength. As shown in this figure, OR operation is simultaneously obtained by selecting the amplified input light.

5. OTHER OPTICAL LOGIC FUNCTIONS

A single-mode bistable laser diode is quite versatile for optical logic functions. Fig. 5 summarizes the optical functions we have achieved. The relation between light output and light input, and the relation between light output and bias current injected into the active sections are represented using three-dimensional coordinates.

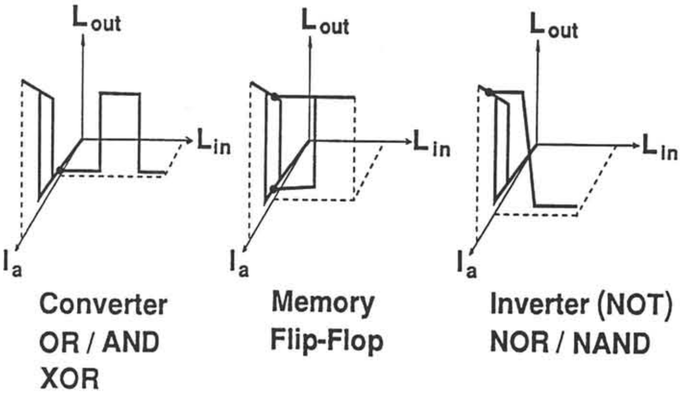

Fig. 5 Various optical functions we achieved.

At the left, the bias current is set below turn-off threshold so that lasing starts with light injection and then stops by gain-quenching. Using these characteristics, optical AND/OR functions are obtained, as well as wavelength conversion and XOR. In the center diagram, the bias current is set in the hysterisis region. This bias condition provides optical memory and optical flip-flop functions. At the right, the bias current is set above turn-on threshold so that lasing output is supress by light injection. This phenomenon produces optical NAND/NOR functions, as well as optical inversion. Thus, this device can realizes many different optical functions by only changing the bias position of the active sections.

For constructing the photonic switching or computing systems, cascadability is very important. When the devices are connected in cascade, the lasing output becomes the light input for the next stage. Our device can be easily connected in cascade by only changing the lasing wavelength at each stage.

Two-dimentional array is also the important direction. There are several ways to fabricate the two-dimentional array, such as 45° mirror type, second-order grating type, and surface emittinng laser. Especially, the micro-cavity surface emitting laser with saturable absorber is very attractive because of its extremely low power consumption.

6. SUMMARY

In a bistable laser diode, lasing and quenching occurred in sequence by controlling light injection. Using these phenomena, we demonstrated a wavelength converter, and various optical logic functions such as inverter and XOR. Thus a single longitudinal-mode bistable laser, in combination with wavelength tuning and wavelength selection, provides a new direction for photonic devices, and play an important role in constructing wavelength and time division multiplexing photonic switching, computing, and optical communication systems.

7. REFERENCES

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