論文の内容の要旨

論文題目　Photonic Integrated Circuits Using All-Optical Flip-Flops Based on Interferometric Bistable Laser Diodes
（干渉型双安定レーザによる全光フリップ・フロップを用いた光集積回路）

氏名　　武田　浩司

Bistable laser diodes (BLDs) have a long history. It has been well known that a continuous-wave operation of a semiconductor laser at the room temperature was first achieved in 1970, whereas the histories of BLDs were already found in 1964. First BLD had two separated p-contact regions called an absorptive BLD, which was constructed from a light emitting contact and an absorbing contact. Due to a carrier-density-depend absorption in the absorbing region, the absorptive BLD has two different stable states of on and off with a same DC injection. The absorptive BLD can be all-optically triggered to be the on state, so that there have been expectations to use BLDs as all-optical logic devices.

After demonstrations of the absorptive bistable lasers, two-mode bistable lasers were realized, which had two different lasing states in a laser cavity. The two-mode BLDs can be switched between each mode triggered in optical domain. The switched state is kept even after the triggered pulse owing to the bistability. Around the same time, additional waveguides enabled all-optical reset function to the absorptive BLDs. Under developments of these two types of BLDs, the BLDs have been expected to play all-optical memory roles by their latching function. An all-optical flip-flop using BLD is a keyword of this thesis, because the flip-flop supplies a memory function.

Another keyword is a photonic integration. Ideas of photonic integrated circuits (PICs) are already found in 1969. It has been claimed that the photonic integration has many advantages; it can reduce a number of components. Smaller number of components means less packaging cost. Smaller number of components uses less number of temperature controllers, which enables drastic diminishing of the power consumptions. In addition, monolithic integration approach realizes reduction of fiber-to-waveguide coupling, which is a major factor to determine optical loss through a chip. Using these advantages, the photonic integrations have been mainly applied to the transmitter and receiver chips, because they are the most important application of the photonics. Especially after the practical realization of wavelength division multiplexing (WDM), a number of elements in transmitters has been drastically increased in order to generate and detect multiplexed signals, so that the photonic integration becomes more important. Recently there have been many attempts to integrate multiple elements into a single chip using monolithic approach. Several venture companies

start up and have succeeded.

Until this moment, all-optical memory element has not been photonic-integrated. Thus a PIC requires real-time processing. The BLDs have been expected to be integrated with other optical devices to act as all-optical memory elements in future PICs, owing to their latching abilities.

In this thesis, I present an all-optical flip-flop (AOFF) based on interferometric BLD to use it as an all-optical memory device in a PIC. Because the AOFF has waveguide structure and it does not require cleaved facet, the interferometric BLD can be integrated with other waveguide devices. I integrate the AOFF with a Mach-Zehnder interferometer (MZI) semiconductor optical amplifier (SOA) switch and demonstrate an application of all-optical packet switching on a single chip with an all-optical memory function.

Chapter 1 presents introduction and background of the research. Previous researches on AOFFs are introduced. Since the PIC is constructed from waveguides, methods for waveguide analysis are described in Chapter 2. The slab waveguide analysis and beam propagation method are mainly presented. Chapter 3 describes fabrication processes of the PIC. I used InGaAsP/InP based materials. The processes are divided into two steps: (1) crystal growth, active/passive and DBR integration, and (2) waveguides and electrodes formations.

From chapter 4 to 6, I describe experimental results. Chapter 4 treats a multimode interference (MMI) coupler based AOFF. It is based on the two-mode BLD using an active 2×2 cross coupler. Both static and dynamic demonstrations are shown with wavelength dependences, wavelength tunability, and polarization insensitive operations. Distributed Bragg reflectors (DBRs) are monolithically integrated with the AOFF. Single-mode lasing is obtained with a 3.1-nm tuning range. The MMI-BLD can be driven with a wavelength range of 48 nm. A rising and falling times of the AOFF are 280 and 146 ps, respectively.

Chapter 5 shows an AOFF based on a BLD with an MZI structure. The MZI-BLD has high tolerance to fabrication errors. I introduce demonstrations of both static and dynamic operations with two-mode lasing. The operable wavelength range is 58 nm. The device is driven by 2.5-pJ optical pulses with rising and falling time of faster than 319 and 68 ps, respectively. In order to discuss limiting factors of the device, a numerical model of the MZI-BLD is described based on coupled rate equations.

Finally, I demonstrate a photonic integrated circuit for single-chip all-optical packet switching in chapter 6. The MMI-BLD type AOFF and MZI-SOA switch are monolithically integrated on a same chip without any additional processes. The AOFF acts as a memory device to drive the switch. 10-, 40-, and 160-Gb/s optical packet can be switched by the PIC with error-free operations in all data rates. It shows that the PIC is transparent to the data rate, and the PIC supports multi-color packets.