Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 165-168

Optical Tristability Using a Twin-Stripe Laser Diode

Masanobu Watanabe, Hideo Itoh, *Masami Saito, Seiji Mukai,
Hiroyoshi Yajima, and *Shin-ichiro Uekusa

Electrotechnical Laboratory,
Tsukuba Science City 305, Japan

*Meiji University
Higashi-Mita, Tama, Kawasaki 214, Japan

Optical tristability is demonstrated with a positive feedback system composed of twin-stripe laser diode, p-i-n photodiode, and transistor. A novel nonlinearity in the light/current characteristics is the key point to realize the tristability. The system is suitable for monolithic integration. Multi-valued logic will reduce the complexity of interconnection in integrated circuits, and it may present a new concept of optical computer architecture.

§ 1. Introduction

Optical bistability and the associated switching and differential gain on semiconductor lasers are essential to the optical digital computing. A lot of works on optical bistability have currently been reported.[1-3] Only few works have been done, however, on the optical multi-stability.

Multi-valued logic offers advantages over binary logic in the design of digital systems because more information can be transmitted over a given set of lines or stored for a given register length.[4] It will contribute to the reduction of the complexity of interconnections in electronic computers. The interconnection delay of inter- or intra-chip is anticipated to limit the speeds of VLSI in the near future because of the decreasing circuit element sizes and increasing chip sizes.[5] The optical interconnection will reduce the signal delay problem because the propagating speed of optical signals is not affected by the capacitance of the interconnection line and the load.[5] In addition, other features of lightwaves, such as parallel signal delivery and free-space propagation also contribute to the reduction of the interconnection complexity.

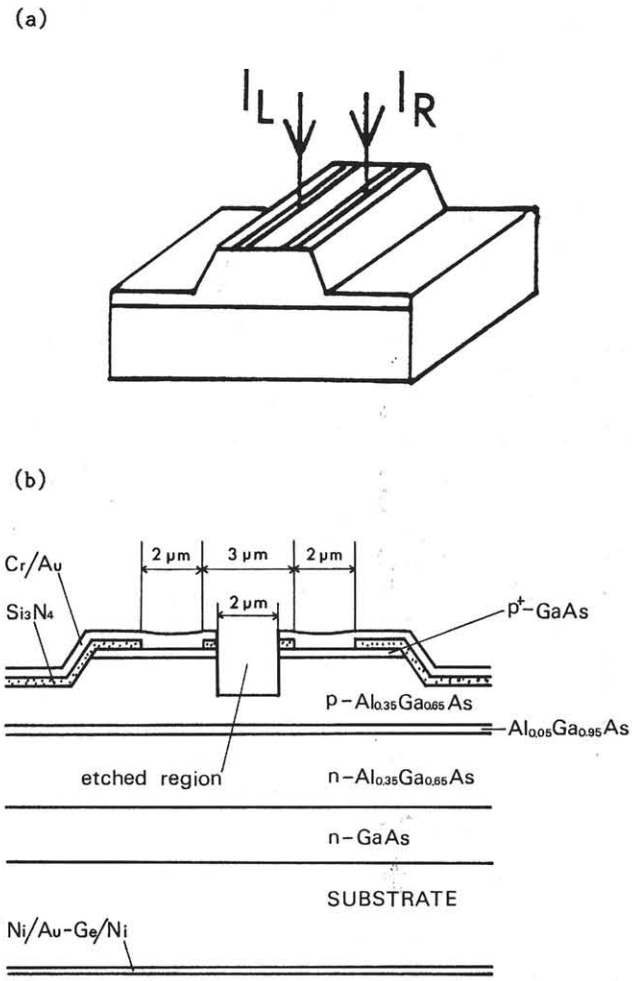

Fig.1 (a) A scheme and (b) a cross section of the twin-stripe laser.

In this work, we have demonstrated an optical tristability using a positive feedback system composed of twin-stripe laser diode[6], p-i-n photodiode and transistor. The system is suitable for the monolithic integration. It can be driven even by an incoherent light. The system presents several features such as tristability, bistability and differential gain by changing system parameters.

§ 2. Experimental

The structure of the twin-stripe laser is shown in Fig.1. It has a pair of striped electrodes with 2-μm width and 5-μm center-to-center spacing. The space between the two electrodes was etched to achive the isolation. The carrier distribution in the active layer can be controlled by changing the current ratio.

A novel nonlinear I-L characteristics of the twin-stripe laser is obtained when the injection current on either one of two electrodes is fixed at a few tens of miliamperes as shown in Fig.2.[7] The negative slope in the I-L characteristics is caused by the slip-out of the transverse-mode pattern from the current distribution.[7] The nonlinearity in the I-L curve offers a possibility of the hysteresis if the output power is positively fed back to the injection current.

Fig.3 shows the positive feedback circuit used in our experiments. The principle of operation is as follows. The p-i-n photodiode receives both the power from an external light source Pi and from a twin-stripe laser Po. The base-emitter voltage of the transistor V_{BE} is proportional to the input power into the photodiode, i.e. $V_{BE} \propto Pi+T \cdot Po$, where the T is the transmissivity of the optical filter. The V_{BE} controls one of the currents I_L of the twin-stripe laser. The I_L is proportional to $Pi+T \cdot Po$ at the low power level, and is constant at the high power level because of the saturation of the transistor. The saturation level was adjusted by the collector voltage Vc. The feedback factor can be varied by changing the resistance R or the transmissivity T. The filter, the p-i-n photodiode and the transistor act together as a light-current converter; its function is shown for four values of Pi by broken lines in Fig.4. To explain the principle of tristable behaviour, the I-L characteristics of the twin-stripe laser is also shown in the figure by a solid line. One of the intersections of the solid and broken lines gives an actual current I_L and an output power Po. As the Pi increases from zero to Pi_1, the

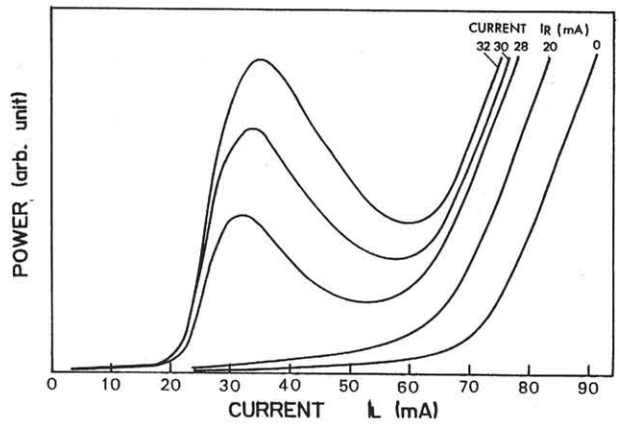

Fig.2 Light/current characteristics of the twin-stripe laser.

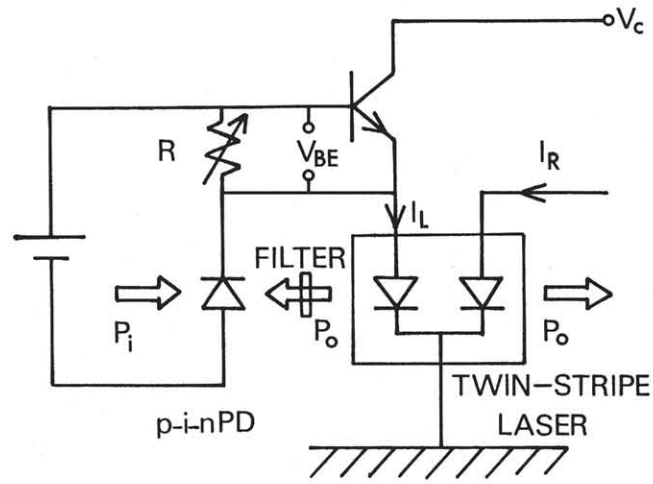

Fig.3 Positive feedback circuit used in the experiment. The I_R is fixed and the I_L is determined by Pi and Po.

Po stays at zero. Then the Po jumps up to Po_1 at $Pi=Pi_1$, and to Po_2 at $Pi=Pi_3$. For $Pi>Pi_3$, the Po stays at Po_2. When the Pi decreases, Po jumps down to Po_3 at $Pi=Pi_4$, and to zero at $Pi=Pi_2$.

§ 3. Results and Discussion

The hysteresis loop indicating tristability has been achieved experimentally as shown in Fig.5(a). I_R and Pi are a rectangular and a half-sine wave of 200 μs duration, respectively, as shown in Fig.5(b). The response speed of the system is limited by that of the photodiode and the transistor. By replacing them with faster ones, the response of the system will be improved.

The slope of the broken line in Fig.1 can be varied by changing the R or the T. By changing the slope and/or the saturation current of the I_L, other functions such as differential gain, bistability etc. are also achieved. Possible functions are shown in Fig.6. Fig.6(a) and (b) shows the tristability and the differential gain, respectively. Fig.6(f) and (i) shows the cyclic types of tristability. Other figures show new logical states given by combinations of bistability and differential gain. These logical states of the system will provide a new concept of optical computer architecture.

The functions of this system, tristability, bistability and differetial gain, can also be switched to each other by changing the I_R. For example, the reduction of the I_R can switch the function from the tristability shown in Fig.5 to the bistability shown in Fig.7. It is due to the disappearence of the negative-slope area in the I-L characteristics.

§ 4. Conclusion

Optical tristability has been demonstrated using a twin-stripe laser diode with a positive feedback. Nine functions including tristability can be obtained by changing the feedback factors such as the transmissivity T, the resistance R, or the injection current I_R. The present system is suitable for monolithic integration, and it can reduce the problem of

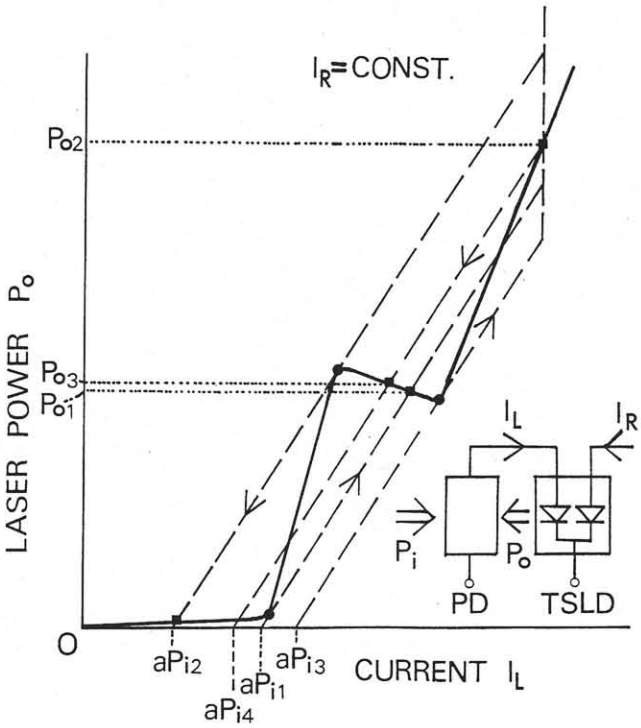

Fig.4 Output power vs. current I_L for a twin-stripe laser(soled line) and characteristics of a light-current converter (broken lines). a: light-current conversion factor of the photodiode and the transistor.

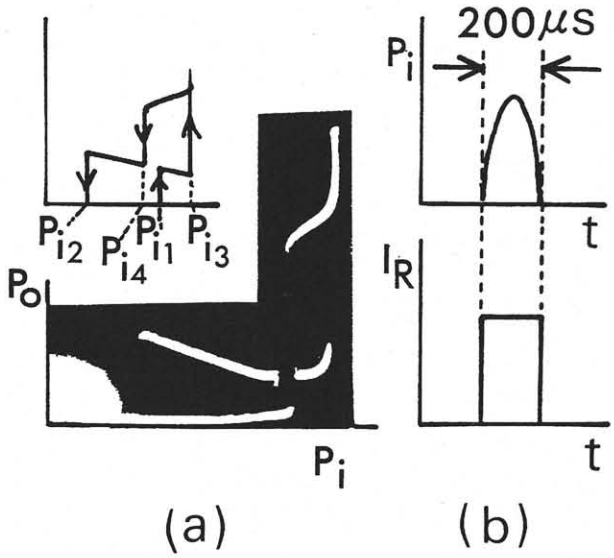

Fig.5 (a) Typical tristability result.
(b) Current I_R(=30mA) and input power Pi

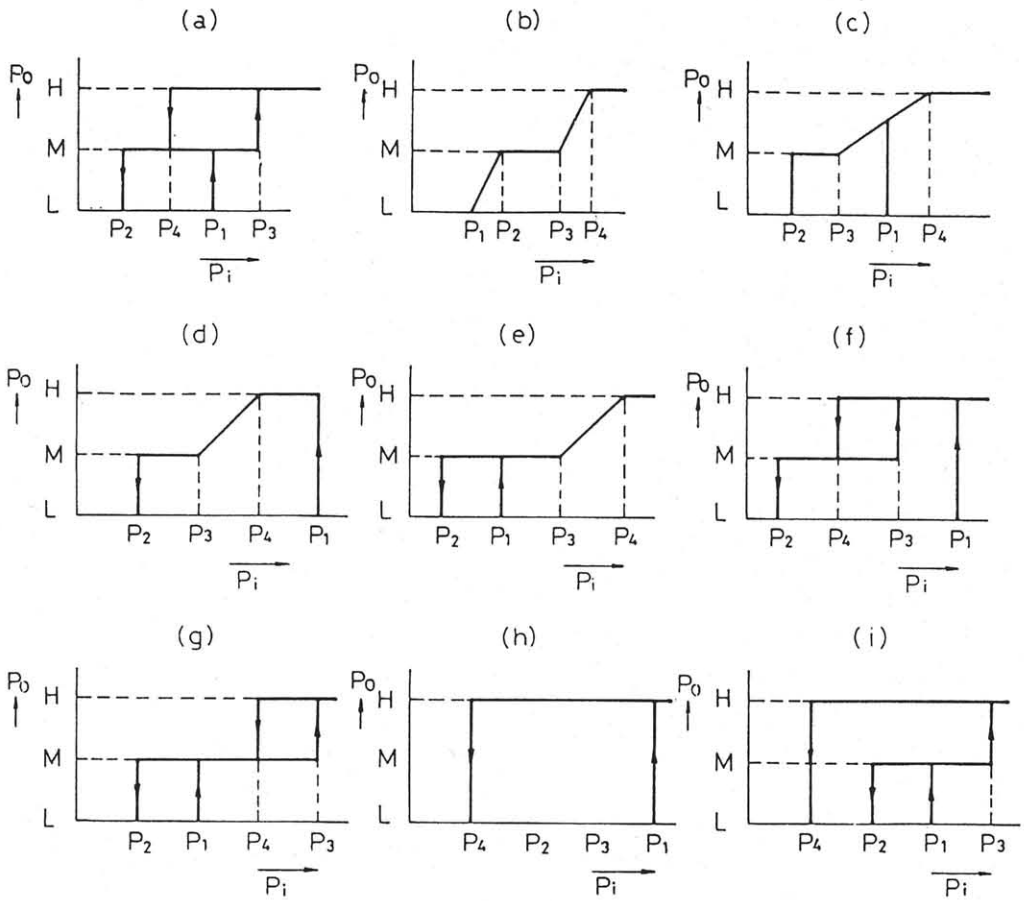

Fig.6 Possible functions of the present three-valued system. Any of them are selected by adjusting the feedback factor (T or R) and/or the saturation current.

interconnection delay. It can be a key device of optical digital computer.

We are grateful to Kiyoshi Asakawa of the Optoelectronics Joint Research Laboratory for etching process of the chips.

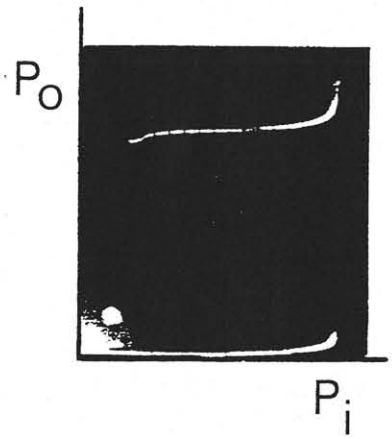

Fig.7 Bistability which occurred with a small I_R(=20mA).

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