Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 601-603

A Novel Optoelectronic RS Flip-Flop Based on Optically Coupled Inverters

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An optoelectronic RS flip-flop has been proposed and differential optical switching has been demonstrated. The RS flip-flop consists of two optical inverters. The optical inverter consists of a parallel connection of a heterostructure phototransistor (HPT) and a light emitting diode (LED) with the load resistor connected electrically in series to them. Optical interconnections are used to couple these inverters. Stable operation with large allowance for bias voltage is demonstrated, which indicates the possibility for 2-dimensional integration.

1. Introduction

There has been much interest in optical parallel processing such as optical digital computing and optical interconnection. Especially in the optical digital computing, it is useful to apply differential switching. For realizing the optical digital computing, the flip-flop operating with optical input and output is also important, and several flip-flops have already been proposed[1-4]. Among them, the optically erasable photonic parallel memory (OE-PPM)[1], the differential optical switching device[2] and the bistable laser diode[3] emit output light by themselves. The output of OE-PPM is not differential, that is, the switch emits light only in the on-state. On the other hand, the differential device emit differential output, which is desirable in some applications and essential in the optical digital computing based on double-railed logic[5]. However, both the outputs can be "on" under some bias conditions since differential operation takes place between two bistable switches. As a result, the margin for bias voltage is small, which may cause array operation difficult. The output of the bistable laser diode is large on/off ratio because it has large optical gain. However, strict temperature control is needed in operating the bistable laser diode. S-SEED[4] does not emit output light although the output of S-SEED is differential. In this paper, we demonstrate a novel optoelectronic RS flip-flop (RS-FF) operated differentially and emitting output light in which two inverters are coupled with optical interconnection. The RS-FF has large tolerance for the variation of bias voltage, which is suitable for 2-dimensional integration.

2. Operation principle

The equivalent circuit of the RS-FF is shown in Fig. 1(a). The RS-FF contains two optical inverters each of which consists of a parallel connection of a light emitting

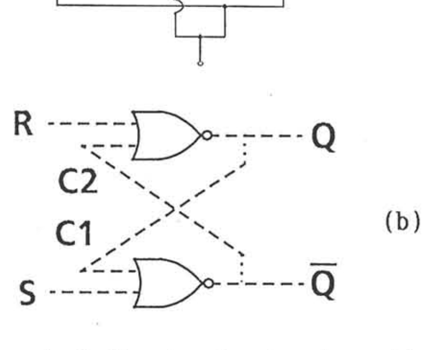

Fig. 1 (a) Equivalent circuit of the RS-FF which consists of two optical inverters. The LED in an inverter and the HPT in the other inverter are interconnected optically. (b) Logic diagram of the RS-FF.

diode (LED) and a heterostructure phototransistor (HPT) that have a load resistor connected in series. Only one of the inverters emits output light over the bias voltage at which the gain of the optical inverter becomes more than unity. The total gain of the optical inverter is determined by the efficiency of an LED in one inverter and the gain of an HPT of the other inverter. The output light of the LED can be turned off by the input light above certain threshold intensity on the HPT connected in parallel with the LED in the optical inverter. Then, most current flows through the HPT because the generated photocurrent is amplified in the HPT, and the LED stops emitting the output light by limiting the current through it. The relation of the input and output power is shown in Fig. 2 by the solid line.

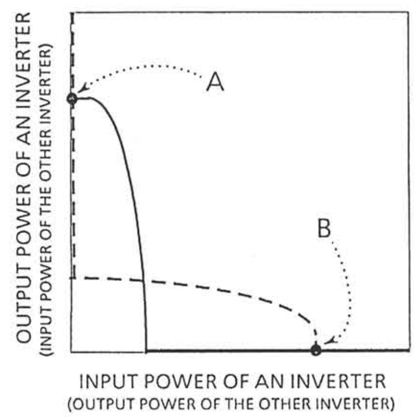

Fig. 2 The relation of the input and output power for an inverter. The solid line is for an inverter and the dashed line is for the other.

When the input power is small, the gain of the HPT is so small that the decrease of output power caused by the increase of input power is very few. However, the gain of the HPT becomes great as the input power is increased and most of the current flows through the HPT, and the LED stops emitting the output light. The input power necessary for turning off is small enough for the output power because the HPT have gain. In the RS-FF, there is another optical inverter, and a portion of the output light is the input light each other. The relation of the input and output power for another inverter is shown in Fig. 2 by a dashed line. From Fig. 2, it is easy to understand that the RS-FF has bistability. The point A is the state in which one inverter emits the output light and the point B is the state in which the other inverter emits the output light. Therefore, the inverters in the RS-FF operate differentially. When the input light from the outside is incident on the HPT of an inverter emitting the output light, the output light is switched.

Only when no input light is incident on an HPT, an LED emits the output light, and the parallel connection of the LED and the HPT with the load resistor becomes a NOR gate. A portion of output light becomes an input light (C1 or C2) of another inverter. The logic diagram of RS-FF is thus to be Fig. 1(b). It is just the same as an electrical RS-FF except that input (R and S), output (Q and Q) and internal connections (C1 and C2) are all optical signals.

3. Structure

To achieve the high efficiency in optical coupling, the LED in one inverter and the HPT in the other are integrated in a

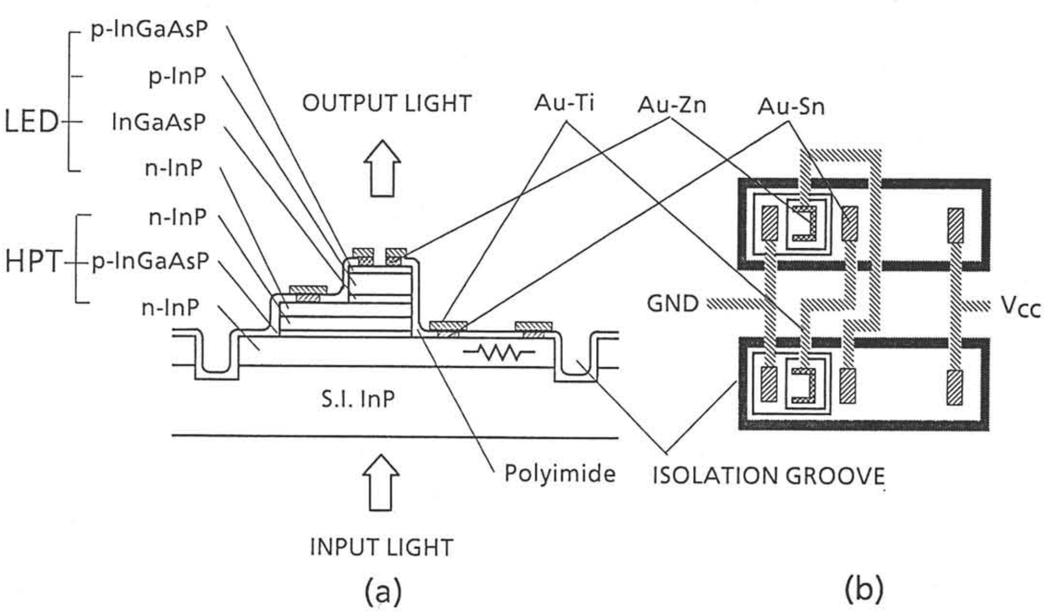

Fig. 3 Schematic cross sectional view (a) and layout (b) of the RS-FF.

single mesa. The mesa consists of seven layers which are an n-InP collector (1.5 μm, 5 x 10^{17} cm^{-3}), a p-InGaAsP base (0.25 μm, 1 x 10^{17} cm^{-3}, bandgap wavelength λ_g = 1.3 μm), an n-InP emitter (0.9 μm, 1 x 10^{17} cm^{-3}), an n-InP clad (0.9 μm, 1 x 10^{18} cm^{-3}), an InGaAsP active layer (0.3 μm, undoped, λ_g = 1.3 μm), a p-InP clad (1.0 μm, 5 x 10^{17} cm^{-3}), and a p-InGaAsP cap (0.1 μm, 2 x 10^{18} cm^{-3}, λ_g = 1.1 μm) as shown in Fig. 3(a). The first three layers form an HPT and the other four layers form an LED. The collector layer is used also as the load resistor. Two mesas are used to construct the RS-FF. The upper mesa of the LED has an area of 18 x 18 μm^2 and the lower mesa of the HPT has an area of 22 x 34 μm^2. The cell size is 100 x 133 μm^2. The layout of RS-FF is shown in Fig. 3(b). The anode of the LED in one mesa is connected to the collector of the HPT in the other mesa to form the parallel connection of the LED and the HPT. An optical inverter constructed with this parallel connection and the load resistor between two contacts on the collector layer.

4. Experiment and result

The optical power necessary to set or reset the switch is measured for the fabricated RS-FF. An external 1.3 μm laser diode is used as a source of set or reset light, which is input from the bottom of the RS-FF through a single mode fiber with a focusing lens. The dependence of the switching power on the bias voltage is shown in Fig. 4. Differential operation is observed at bias voltages above 0.95 V. As can be seen in Fig. 4, the powers to set and reset the output lights are almost equal. Neither LED emits light at voltages less than the built-in voltage (0.7 V). From 0.7 V to 0.95 V, both LEDs emit light. In this range, the total gain of the inverter is less than

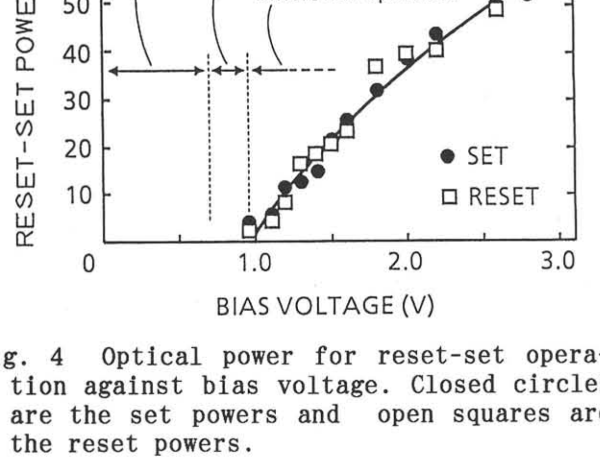

Fig. 4 Optical power for reset-set operation against bias voltage. Closed circles are the set powers and open squares are the reset powers.

unity since the efficiency of LED and the gain of HPT are small.

To measure the dynamic characteristics, optical pulses are input to the RS-FF and the dependence of the switching power on the pulse width is also measured. The switching power increases as the pulse width decreases. It increases as the bias voltage applied to the RS-FF increases. The optical pulse with a width of 20 ns can set or reset the RS-FF at a bias voltage of 0.95 V. At the same bias voltage, the switching powers for set and reset are 465 and 375 μW, respectively.

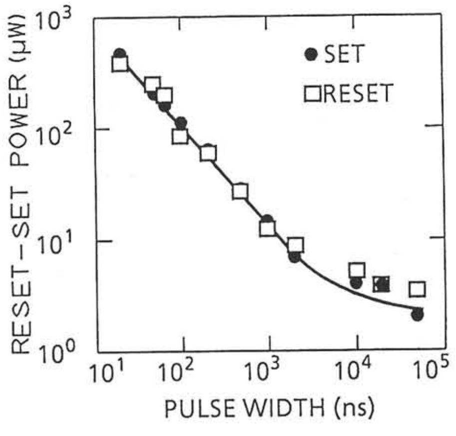

Fig. 5 Optical power for set or reset the RS-FF against the pulse width of the input light. Closed circles are the set powers and open squares are the reset powers.

5. Conclusion

In summary, a novel optoelectronic RS flip-flop based on optically coupled inverters has been proposed and stable operation for the bias voltage has also been demonstrated. The optical pulse with a width of 20 ns can set and reset the RS-FF at a bias voltage of 0.95 V, and the switching powers for set and reset are 465 and 375 μW, respectively, at the same bias voltage. Large allowance for the bias voltage indicates the easiness for 2-dimensional integration.

References

1. K. Matsuda, H. Adachi, T. Chino and J. Shibata, IEEE Electron Device Lett. **11**, No. 10, 442 (1990)
2. K. Hara, K. Kojima, K. Mitsunaga and K. Kyuma, Electron. Lett. **25**, 433 (1989)
3. H. Kawaguchi, H. Tani and K. Inoue, Opt. Lett., **12**, 513 (1987)
4. A. L. Lentine, H. S. Hinton, D. A. B. Miller, J. E. Henry, J. E. Cunningham and L. M. F. Chirovsky, IEEE J. Quantum Electron. **QE-25**, 1928 (1989)
5. A. Huang, Proc. IEEE, **72**, 780 (1984)