전기 광학적 궤환을 이용한 광 쌍안정성과 다 안정성

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Optical Bistability and Multistability Using Electro-Optic Feedback

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ABSTRACT

We demonstrate the optical bistability and multistability using light emitting devices, a photodetector, and transistors under the positive electro optic feedback. Its operating principle and high speed operation scheme are also described.

Intrinic and hybrid optical bistability are demonstrated in various configurations[1]. However, only a few experimental results have been reported for optical multistability[2-6]. The hybrid optical devices based on electro-optic feedback are operated at low optical power with very wide range of wavelengths and any polarizations. Using these attractive features, various optical logics[6-9], flip-flops[6-10], and multistability[5,6] are studied experimentally. Especially, the multivalued logic based on multistability is important to reduce complexity of devices and interconnections since it increases the information capacity of each line and each storage element compared with the binary logic. In this letter, we report the experimental results of the optical bistability and multistability using a light emitting diode, a photodetector, and transistors with the positive electro-optic feedback. The circuits are very simple to integrate and may be of great use as simplest form of multistability in optical digital computers.

Let's first consider the bistability as the simplest form of multistability. To get the optical bistability using semiconductor light emitting devices, photodetector, and electrical active elements under the electro-optic feedback are needs cut-off and saturation characteristics of the devices as well as amplification. The cut-off characteristic was usually implemented by the threshold characteristic of diode laser(LD)[7] or its equivalent in light emitting diode(LED)[8]. Therefore the bias current of the diode laser must be below the lasing threshold current. The saturation and the amplification characteristics were achieved by electronic active elements such as transistors, field effect transistors, and avalanche photodetectors.

We demonstrated optical bistability by using a photodetector, a transistor, and a LED/LD. Unlike the other approachs[7,8] which utilize the threshold of a light emitting device to implement the cutoff characteristic, we use cutoff characteristic of a transistor. Thus, we can bias the diode laser above the threshold to improve the speed of the bistable device. The circuit diagram of the bistable device is shown in Fig. 1. The optical output of the LED/LD is fed to the photodector to obtain positive feedback loop. This feedback output and input photons are converted to current by a photodetector,, and amplified provided that the current is greater than the critical current I_c which is given by

$$I_c = V_\gamma / R_b$$

where V_γ is cut in voltage of the transistor and R_b is the resistance of the resistor which is connected to the base of the transistor. The current gain A which is ratio of the current through the photodetector and that of the collector of the transistor is given by

$$A = h_{FE} \ / \ [1 + kT/(qR_b I_b)]$$

where h_{FE} is the dc current gain of the transistor and regarded as constant over the operation range of the transistor. k is the Boltzman constant, T is absolute temperature, q is charge of a electron, and I_b is the base current of the transistor. The gain decreases as the resistance R_b decreases. To get optical bistability closed loop gain of the feedback loop must satisfy the following condition:

$$1 < A\eta_d\eta_l < 1 + h_{FE} V_\gamma / I_{csat} R_b$$

where η_d is conversion efficiency from optical power to current, η_l is conversion efficiency from current to optical power, and I_{csat} is saturation current of the collector and inversely proportional to the collector resistance R_c. Here η_d contains the coupling efficiency of output optical power of the LED/LD to the photodetector. Physically the lower limit is regarded as the condition of regenerative amplification of the feedback optical power, i.e. the closed loop gain of the feedback loop must be greater than one. The upper limit is condition of excitence of the 'ON' to 'OFF' transition at the nonzero input optical power. If closed loop gain is greater than the upper limit, the input/output characteristic of the device is similar to that of a thyrister in electronics.

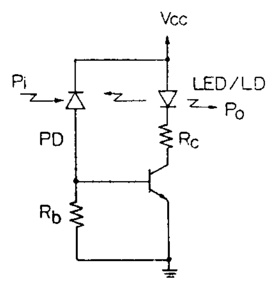


Fig. 1. Circuit diagram of the bistable device

As shown in Eq. (1) transition threshold level from 'OFF' state to 'ON' state depends on the R_b and the reverse transition threshold is obtained by the resistance R_c. By varying the resistance of resistor R_c, we can tune the output optical power of the bistable device and 'ON' to 'OFF' transtion point simultaneously. The tuning characteristic will be utilized to realize optical multistability. Input/output characterisric of the bistable device is shown in Fig. 2 with different values of resistance R_b. $1Hz$ sinewave optical siginal is used as input. Fig 2 (a) and (b) are input/output charcteristics with $1k\Omega$ of R_b and 3 $k\Omega$, respectively, and show decrease of bistable width as resistance R_b decreases which implies the decrease of the gain A.

The simplest approach to get optical multistability is parallel connection of the bistable devices with variable transition threshold levels. We show circuit diagram of the optical multistable devices in Fig. 3. The device consist of a LED/LD, a photodetector, and transistors. The pnp

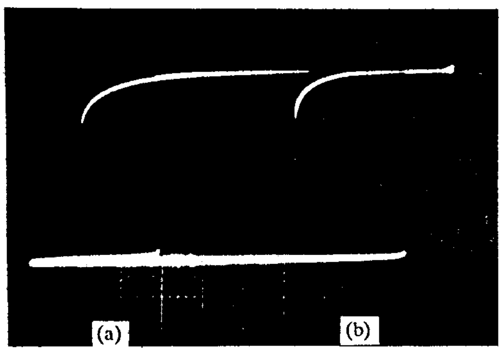


Fig. 2. Input/optput characteristic of bistable device

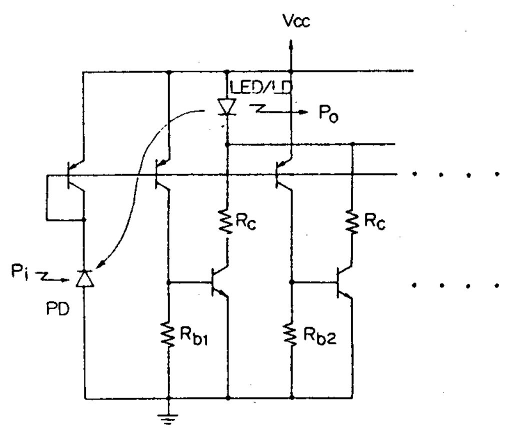
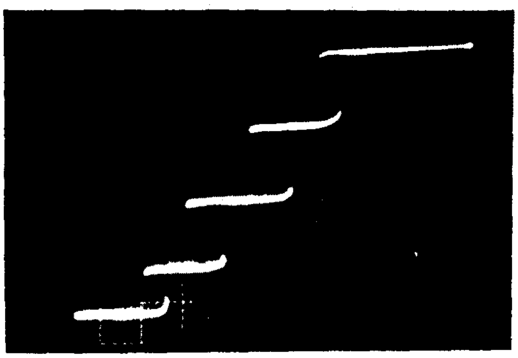


Fig. 3. Circuit diagram of the multistable device

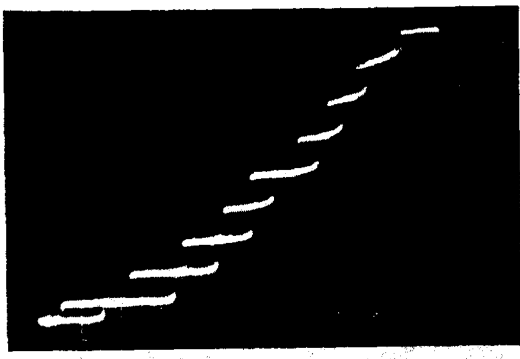
transistors are empolyed to implement simple current mirror[11]. The collector current of each transistor(arms of the mirror) is approximately equal to current of the source transistor, i.e. the tansistor with shorted base and collector terminal. The photodetector is connected to the collector of the source transistor of the current mirror. Thus, the current through one arm of the current mirror is equal to that of the photodetector since the characteristics of every transistor of the current mirror are equal to each other. Therefore, individual arm of the current mirror is equivalent replacement of the photodetector. The the device is equivalent to parallel connections of the bistable devices with variable thresholds. The use of the current mirror insteaded of individual photodetector offers some advantages. First of all, the problem of aligning photodetectors to one LED is removed. And, in the integration point of view, the transistor occupies less area than that of the photodetector. By varying the base resistance R_b, one can tune the transition point of the device continuously.

The input/output characteristics of the optical qunistable and decistable devices are shown in Fig. 4. Here we sinusoidially modulated the input optical signal with $1Hz$. We use the phototransistor instead of photodetector to align easely. The unequal width of hysteresis for the each stage is due to unequal h_{FE} of the transistor and R_b dependent gain. The unequal height between the states comes from the nonlinearity of the photodetector. It is important to note that the dark current of the photodetector and the open-base collector-to-emitter current I_{ceo} must be considered to get proper values of the resistance R_b.

To get the optical multistable device with equal width of the hysteresis, we must compensate the decrease of the gain due to the resistance R_b even though the transistors have same characteristics. A current mirror can improve the speed limitation due to saturation of the transistors. The circuit diagram of the proposed device is shown in Fig. 5. Here we use the another current mirror instead of the collector resistor R_c, and save the area of the chip since the resistors are replaced by the transistor. Since the transistor acts in active region its speed is not limited by the saturation of the transistor. To demonstrate this we show the input/output curves with and without modification in Fig. 6. Fig. 6 (a) takes with the same condition as Fig. 4 (a) except the increace of the frequency of the input optical signal to $100Hz$. By comparing two figure, we can see the increase of the width of the hysteresis of the each stage with increase of scan speed of the input signal. The biggest change of the width can be seen at the first stage which turns on first since it saturates most deeply. Fig. 6 (b) and (c) show the input/output curve of the modified qunistable device with $1Hz$ and $100Hz$ scan frequencies of input, respectively. Here we cannot see any appreciable change of the curve. This is due to the nonsaturate operation of the transistors. It is possibe to solve the saturation problem of



(a) Qunistability



(b) Decistability

Fig. 4. Input/output charcteristic of multistable device

the transistor by using ECL(Emitter Coupled Logic) configuration.

In conclusion we have demonstrated the optical bistability and multistability using the a light emitting device, a photodetector, and transistors. Also its operation principle and high speed operation scheme are described. These devices are very simple to integration and may be uesd as a basic element of digital optical computing as basic elements. And they are insensistive to change of the input wavelength and polarization. To get two dimensional array of the devices it is desirable to make use of surface emitting LEDs/LDs in one side of the array with photodetectors in the other side.

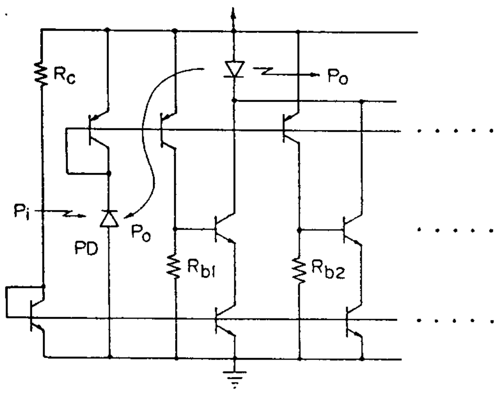
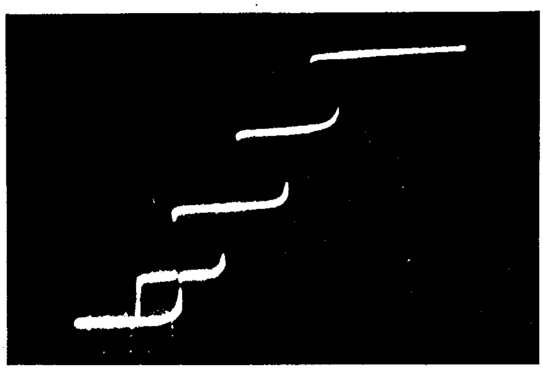


Fig 5. Circuit diagram of the modified multistable device



(a) Before modication with 100Hz scan frequency of the input

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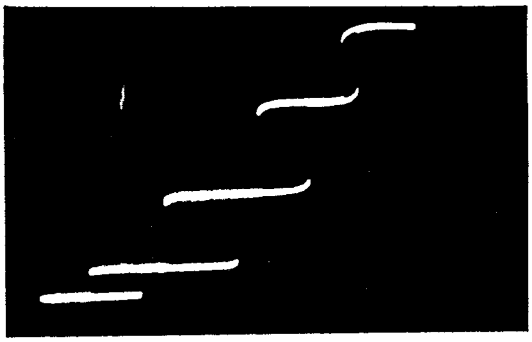
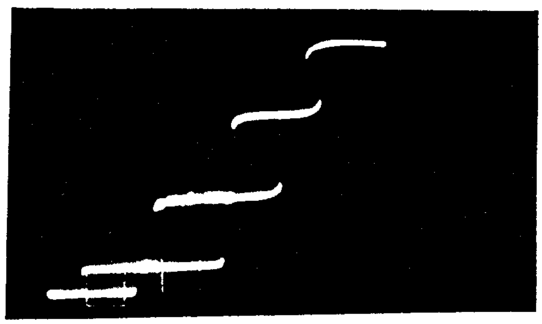


(b) After modification with 1Hz scan frequency of the input



(c) After modification with 100Hz scan frequency of the input

Fig. 6. Input/oputput characteristic of the qunistable device