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Fibre optics hybrid bistable switch

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The fibre optic hybrid bistable switch based on a Ti:$LiNbO_3$ modulator with an external electric feedback was fabricated and investigated. Its properties were found both numerically and experimentally. The influence of the feedback parameters and the characteristics of a modulator on the device operation was examined.

1. Introduction

Bistable switches can perform many important functions in telecommunication and optical computing [1]–[4]. This paper presents hybrid bistable device based upon Ti:$LiNbO_3$ fibre optic cutoff modulator with an external electric feedback added in order to achieve bistability.

The hybrid switches are significantly slower than the pure-optical mirrored devices but they can work on both coherent and incoherent light and their parameters can be easily changed by electrical methods. There has been reported many hybrid bistable switches based on different kinds of modulators but we have found no exhaustive analysis of the operation of a bistable device with the cutoff modulator inside.

The cutoff modulator is one of the simplest and the easiest to fabricate. We investigated how it works as a bistable device and how to control the operation of such a device.

2. The Ti:$LiNbO_3$ cutoff modulator

The layout of the device is shown in Figure 1a. The *Y*-cut $LiNbO_3$ plates with *X* propagating Ti indiffused $LiNbO_3$ waveguides were used for efficient TE mode modulation. Diffusion was carried out at 1050 °C from 10 nm thick, 5 μm wide Ti strip for 4 h in air (the devices were adjusted to operate in 628.8 nm He-Ne laser light). The lengths of the waveguides were from 10 to 12 mm, depending on the sample. The 10 μm wide and 6–8 mm long gold electrodes were placed symmetrically on both sides of a waveguide in the II region of the device.

Input He-Ne laser light was supplied by elliptical, polarization presrving monomode fibre connected to the edge of the waveguide with the UV hardening glue.

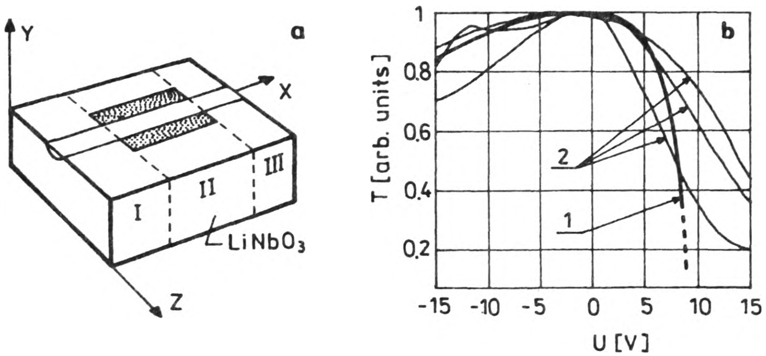

Fig. 1. Layout of Ti:LiNbO$_3$ cutoff modulator (a). Transmission *vs.* voltage characteristics (b). 1 – theoretical characteristics for a device of 1.5 μm channel depth and the refractive index difference between the waveguide and substrate equal to 0.0033. 2 – experimental characteristics of actual devices.

The detailed analysis of the device was published previously [5], [6]; an example of theoretical characteristic and some experimental characteristics of actual devices are shown in Fig. 1b.

3. Analysis of operation of the bistable device

The basic layout of the bistable device is shown in Figure 2. Input light is supplied to the modulator by a monomode polarization preserving fibre. Part of the output power supplies the feedback circuit which consists of a detector, a linear amplifier and a circuit for setting the bias voltage. Operation of such a device is influenced by the transmission *vs.* voltage characteristics $T(U)$ of a modulator and feedback loop parameters: amplification β, output light partition coefficient k and bias voltage U_b.

For the circuit shown in Figure 2, we can define the following equations [7], [8], [9]:

$$P_{in} = \frac{P_{out}}{kT(U)},$$
$$U = \frac{1-k}{k}\beta P_{out} + U_b \tag{1}$$

therefore, and

$$P_{in} = \frac{P_{out}}{kT\left(\frac{1-k}{k}\beta P_{out} + U_b\right)} \tag{2}$$

where P_{in} and P_{out} are input and output light signals, β – amplification of the feedback loop, k – light partition coefficient at the output of the device, U_b – bias voltage.

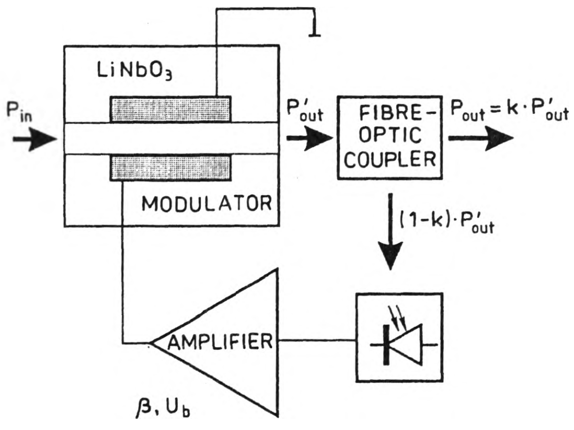

Fig. 2. Layout of the bistable device: k — output power division, β — gain of the amplifier, U_b — constant voltage compound

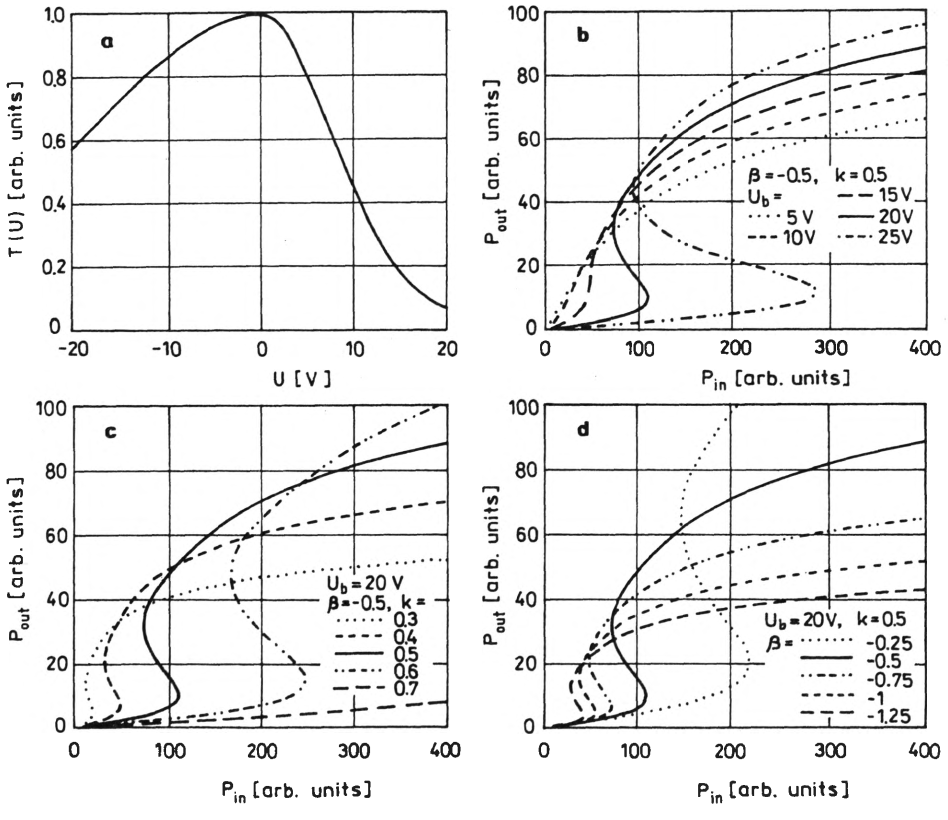

Fig. 3. Theoretical characteristics: **a** — an example of characteristics $T(U)$ of a modulator, **b** — the bistable surface $P_{out}(P_{in}, U_b)$ for β, $k = \text{const.}$, **c** — the bistable surface $P_{out}(P_{in}, k)$ for β, $U_b = \text{const.}$, **d** — the bistable surface $P_{out}(P_{in}, \beta)$ for k, $U_b = \text{const.}$

Since we have three independent parameters β, k and U_b in Eqs. (1) and (2), we can present the switch characteristics in three ways, as: $P_{in} = f(P_{out}, \beta)$, $P_{in} = f(P_{out}, k)$ or $P_{in} = f(P_{out}, U_b)$ bistable surfaces. This representation allows us to discuss seperately the influence of the feedback loop parameters on the properties of a bistable device.

In spite of P_{out} is a function of P_{in}, the computations will be easier if we assume P_{in} to be a function of P_{out} and then rotate the coordinate axes. The numerical analysis of Eq. (2) (curves shown in Fig. 3) brings some information about the behaviour of the device when other parameters change:

1. In the voltage range, where the bistable effect occurs, the feedback gain changes the results mainly in the bistable loop displacement, with only a small change of its width. When the gain increases, the bistable loop moves to the right (Fig. 3**d** and 3**b,d**).

2. Any change of U_b causes both displacement and width change of bistable loop (the greater U_b, the wider the loop and more shifted to the right, see Fig. 3**b** and 3**b,c**).

3. The influence of power divide coefficient k (Fig. 3**c**) is quite significant and different from the influence of β. This effect should be carefully considered in designing of bistable devices.

4. Large inclination of characteristic $P_{out}(P_{in})$ with no bistability can be achieved for this device (Fig. 3**b**, the curve for $U_b = 10$ V); it may be used for some applications [1], [3], [4].

The curves in Figure 3 were plotted on the assumption that the maximum transmission through the modulator is equal to 1. For actual devices, however, those coefficients are much lower. To obtain the bistable curves for different transmission T_0, it is sufficient to multiply the Y-axis scale by T_0.

4. Experiments

A few Ti:$LiNbO_3$ modulators were mounted into the bistable device. The input light from He-Ne laser was formed into a 1 kHz saw-tooth signal by a Bragg bulk modulator and then divided into two parts: one focused on the edge of input fibre of the modulator, and the second one illuminating a detector connected to the X channel of an oscilloscope through detector and linear current-voltage converter. The output light fed the Y oscilloscope channel by identical converter. The values of bistable loop parameters were set up directly on the console of a bistable device. Since the amplifier allows only for setting the constant voltage compound (average voltage), not the bias voltage U_b as in our theoretical analysis, we matched the experimental settings to be equivalent to the given U_b values.

The experimental results achieved agreed well with theoretical assumptions. Some examples of experimental characteristics are shown in Fig. 4.

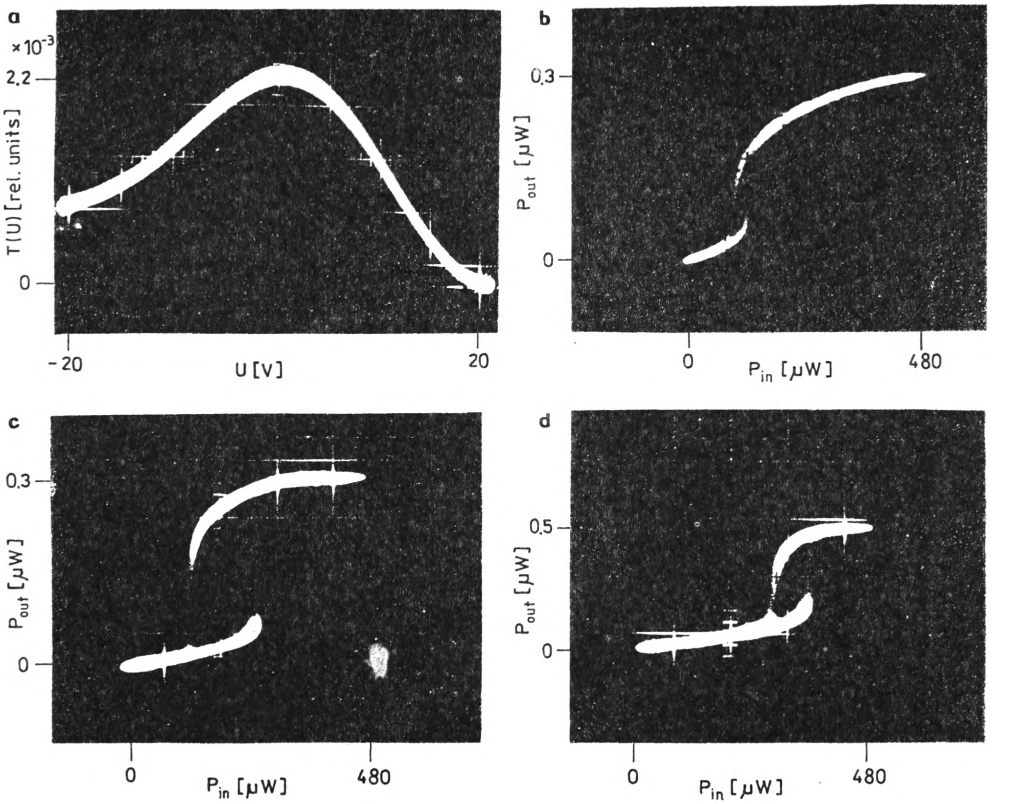

Fig. 4. Experimental characteristics: a — the characteristic of the M912 modulator, b — the bistable effect for $U_b = 20$ V, $\beta = 5.4 \times 10^7$ V/W, c — the bistable effect for bias voltage $U_b = 25$ V, $\beta = 5.4 \times 10^7$ V/W, d — the bistable effect for $U_b = 20$ V, $\beta = 2.4 \times 10^7$ V/W (changed scale). k coefficient is equal to 0.5 for all cases

5. Conclusions

The main properties of the bistable device were found numerically and experimentally. We established that the bistable loop shape can be adjusted to given requirements, and showed that this shape can be controlled in a wide range by appropriate matching of strictly electrical parameters, *i.e.*, U_b and β. This feature can be useful for some applications which require a great elasticity or precise tuning. Special attention should be paid to the setting of output power divide coefficient since it affects not only the amount of output usable power, but also the shape of bistable loop of a device.

Some more investigations should be done in order to improve poor transmission efficiency of our Ti:LiNbO$_3$ cutoff modulators caused mainly by weak fibre-to-waveguide coupling. This is important to provide sufficient level of output signal and to improve the speed performance of the device (since the possibilities of the feedback amplifier are limited by the gain-bandwidth product).

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