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PHOTODETECTOR ON THE BASE OF UNI-JUNCTION TRANSISTOR AND PHOTO-DIODE

Uni-junction transistor, often named two-base diode consists of the semiconductor plate with two Ohmic contacts and *p-n*-junction. Charge carriers, injected from the emitter change the resistance between the base contacts that causes the change of the current J_{B1B2}, namely the output current. Input (the circuit *p-n*-emitter – the base B_1) volt-ampere characteristics of uni-junction pertains to the *S*-type [1]. Such transistor is the simplest element playing the role of the base for construction of the generator of the relaxation oscillations. The scheme of this generator contains the minimal number of the elements, and thus, is simple and stable in operation.

The converters of the different physical values (light, temperature, pressures, etc.) with the frequency output on the base of the uni-junction transistor are broadly used in the technique [2]. The generators on the base of the uni-junction phototransistor (UPhT) are used as the sensor-photo-detectors with the frequency output. The linear dependence of the frequency on the intensity of the light flow and the sensitivity to the weak light signals are the actual problem in this case.

The characteristics of the combined photo-detector on the base of the UPhT with the photo-diode in the input circuit, offered in [3], with the scope of the photosensitivity enhancement and the achievements of the characteristics of the frequency-light's intensity are discussed in this work. Schematic design of the cubic structure photo-detector is presented on Fig. 1.

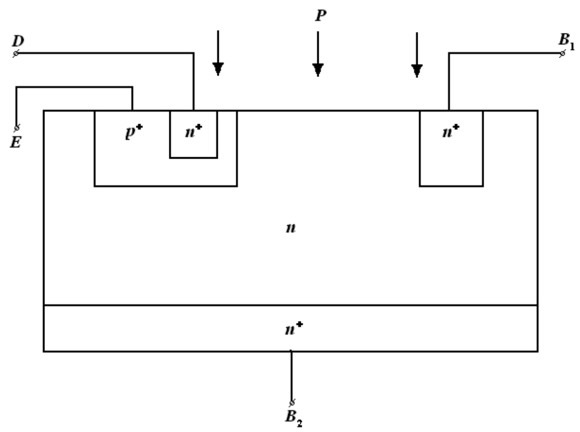

Fig. 1. Scheme of UPhT construction

The semiconductor crystal of the n-type conductivity contains two Ohmic base contacts of the n^+-type conductivity (contacts B_1 and B_2), as well as injection emitter *p-n*-junction *E* (the region of the p^+-type) with the electric connectors. Unlike the known design the addition n^+-region *D* is created in the p^+-region.

The work of the UPhT in the scheme of the relaxation generator of the vibration is possible to illustrate as follows (Fig. 2).

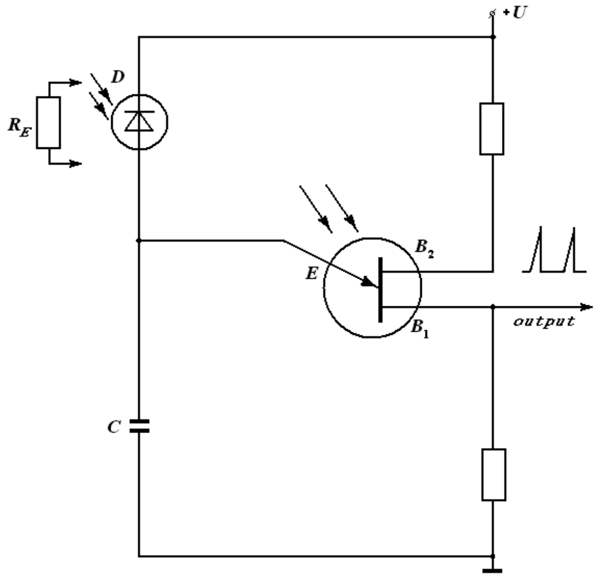

Fig. 2. Generator of the relaxation oscillations

The capacitor C in usual scheme of the relaxation generator in the circuit of the emitter's network is charged through resistance R_E. The frequency of the vibrations is defined as

$$f = \left[R_E C \ln \frac{U - U_0}{U - U_t(P)} \right]^{-1}, \tag{1}$$

where U_C, U_0 – voltage of the connection of the emitter and the remaining voltage on it in the switching on condition, U – voltage of the power supply.

The capacitor C is charged when the power source is switched on. The injection through p-n-junction increases in avalanche way, when the capacitor C is charge to turn-on voltage V_t. The discharge of the capacitor C happens after this, through the circuit E-B1. The structure is switched on after the discharge on the capacitor and the current in the input circuit decreases, the process of the changing of the capacitor begins once again and again. As the values U0 and Ut are stable as to the changes of the temperature, therefore period and frequency of the oscillations of the relaxation generator are enough stable. At the illumination of a part of the semiconductor crystal between the emitter E and the base B1 causes the voltage of the switching on Ut to be the primary parameter, which depends on the intensity of the light flow P. The voltage of switching $U_t = I_{B1B2} \cdot r_{B1}$, where rB1 – is the resistance of the input element of the UPhT's base, I_{B1B2} – the current of the base. The resistance rB1 is decreased as the photo-resistor is illuminated what leads to the decrease of the voltage Ut(P). As follows from (1), the frequency of the oscillations f, starting from voltage U0(P), increases nonlinearly with the growth of the light flow.

In present work, we propose to use the generator of the relaxation oscillations voltage drop instead of resistor R_E, the bias of the p^+-n^+-diode (the circuit *E-D*, Fig. 1), where a saturation current generator is placed in the circuit of the emitter power supply. The current practically does not depend on the voltage. In this case the current during charge of the capacitor *C* is constant and the voltage drop on it increases linearly in time. The equation (1) is, thus, simplified considerably:

$$f = \frac{I_S}{C(U_t - U_0)} \approx \frac{I_S}{C \cdot U_t}, \quad (2)$$

since usually $U_t >> U_0$. Here I_S — the reverse-bias current (the saturation current) of the p^+-n^+-junction.

At illumination switched on, at one hand, as it is shown above, the voltage of the switching on U_t(P) is decreased. At the other hand, the reverse-bias current grows with the value of the photocurrent I_{Ph} at illumination of the p^+-n^+-junction. Accordingly, the frequency of the output signal oscillations under illumination

$$f = \frac{I_S + I_{Ph}}{CU_{CPh}}. \quad (3)$$

As it is well known, the photocurrent of the photodiode is described by linear dependence on the intensity of the light flow *P*.

We should note, also, one particularity of the combined photo-detector. The *n-p*$^+$-*n*$^+$-structure in input circuit (B_2-*E-D* electrodes, Fig. 1) acts as bipolar transistor, current of the collector which under illumination is equal to $I_S + I_{Ph}$. This current is multiplied by the value of the amplifier's coefficient $\beta = 1/(1-\alpha)$, where α is the coefficient of the current's transfer of the transistor in scheme with the general base [1]. Thereby, under $I_{Ph} >> I_S$ the frequency of the relaxation generator at the illumination of the combined photo-detector equals to

$$f_{ph} = \frac{\beta I_{ph}}{CU_{ph}}. \quad (4)$$

The relative change of the generator's frequency at illumination is $I_{Ph}\beta/I_S$ times greater, than in usual UPhT (with resistor R_E in emitter circuit). Taking into account that the coefficient of the transfer α weakly depends on the illumination intensity, it is possible to consider that the frequency of the generator based on the oscillations photo-detector changes linearly with the intensity value of the light flow.

The combined photo-detector on the base of silicon crystal of the cubic form with size 200×200×200 μm was studied experimentally (Fig. 1). The sizes of contacts were as follows: B_1 — 100×40 μm, B_2 — 200×200 μm, emitter *E* (p^+-type) — 100×40 μm, the additional n+-region (*D*) — 50×20 μm. The illumination of the samples was provided with the infrared light-emitting diode AL119B (λ = 0.93...0.96 μm). Power of the radiation of the light-emitting diode at the current value of 300 mA was not less than 40 mW. The practically linear graph of the dependence of the emitter's voltage switching on U_t(P) on the light flow intensity *P* is presented at Fig. 3.

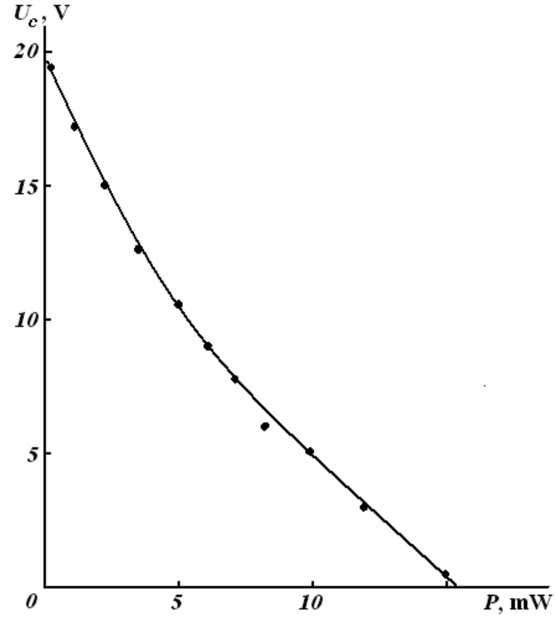

Fig. 3. Dependence of the emitter's turn-up voltage on the intensity of light

The dependence of the relaxation generator frequency *f* on the illumination intensity is presented at Fig. 4. The curve 1 was measured for the case, when the electrode *D* is switched off and the resistance R_E is switched on in the circuit of the emitter's power supply, i.e. for the simplest scheme of the UPhT's relaxation generator. The sensitivity of the frequency $K = \Delta f/\Delta P \approx 0.5$ kHz/mW. The dependence *f*=f(P) for the combine photo-detector is presented by curve 2, Fig. 4.

It could be seen that this dependence is practically linear and the sensitivity on frequency is much higher ($K \approx 7$ kHz/mW).

It should be noted that the presence of additional bipolar photo-transistor in scheme of the combined photo-detector does not define significant increase of the photo-signal since for bipolar structure specified in this case and the coefficient of the current transfer α is not large due to small value of the injection's coefficient. However, even though $\alpha \approx 0.5$, the amplifier's coefficient $\beta \approx 2$. The respective contribution to the increase of the photosensitivity of this structure could be achieved as the result of addition al structural element inclusion.

Thus, we have shown the possibility to raise the linearity of the output signal and enlarge the sensitivity of the sensor on the base of uni-junction photo-transistor through introduction of the additional n^+-region into p^+-emitter of the photo-transistor.

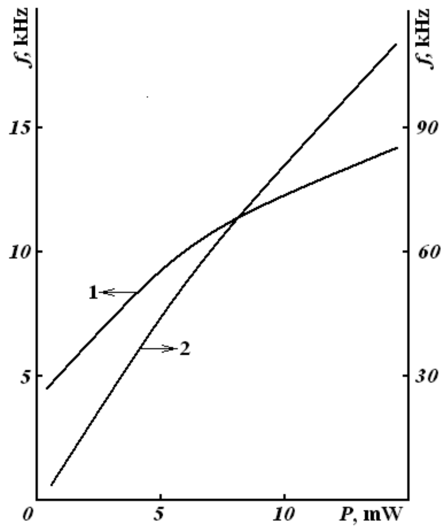

Fig. 4. Dependence of the frequency on the intensity of light 1 — regular UPhT, 2 — combined photo-detector

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ФОТОПРИЕМНИК НА ОСНОВЕ ОДНОПЕРЕХОДНОГО ТРАНЗИСТОРА И ФОТОДИОДА

Генераторы на основе однопереходных фототранзисторов (ОФТ) используются в качестве сенсоров–фотоприемников с частотным выходом. Полупроводниковый кристалл *n*-типа проводимости содержит два омических базовых контакта n^+-типа проводимости, а также инжектирующий эмиттерный *p-n*–переход (область p^+-типа) с электрическими выводами. Показана возможность повысить линейность выходного сигнала и увеличить чувствительность датчика на основе однопереходного фототранзистора введением дополнительной n^+–области в p^+-эмиттер.

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ФОТОПРИЙМАЧ НА БАЗІ ОДНОПЕРЕХІДНОГО ТРАНЗИСТОРА ТА ФОТОДІОДА

Генератори на базі одноперехідних фототранзисторів (ОФТ) використовуються в якості сенсорів-фотоприймачів з частотним виходом. Напівпровідниковий кристалл *n*-типу провідності містить два омічних базових контакти n^+-типу провідності, а також інжектуючий емітерний *p-n*–перехід (область p^+-типу) з електричними виводами. Показана можливість підвищення лінійністі вихідного сигналу та зростання чутливості датчика на базі ОФТ шляхом введення додаткової n^+-області в p^+-емітер.