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EXPERIMENTAL STUDY OF THE POSSIBILITY OF USING DISCRETE LEDS AS LIGHT SENSORS

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Abstract
The development of electronics and in particular sensor technology requires an increasing demand for possibilities for converting non-electrical quantities into electrical ones. Optoelectronics is one of the most developed areas in the field of functional electronics. It allows for the conversion of many non-electrical quantities into electrical ones. Of interest to optoelectronics and sensor technology is the possibility of using the same type of converter – an LED, as a light source and as a light sensor. In this report, some experimental setups and results are presented and described, proving the possibility of converting the electrical signal into light and light into an electrical signal with the same converter – a standard discrete LED.

Keywords: semiconductor light sources, LEDs, photodiodes, generation of current carriers, recombination of current carriers, optocouplers, photoelectric effect

INTRODUCTION

LEDs have found wide application in various fields of science and technology. The light emitted by them is of a discrete nature, which allows their use not only as light sources [2] (illuminators), but also as transmitters of information through light [11]. Various developments are known, reflecting the advantages of LEDs in science and technology [5, 6].

There is a great variety of LEDs. They are classified according to various characteristics, which are well described in [1], and in [4-6] specific applications of LEDs in sensor technology are also considered.

Of interest for electronics and in particular for sensor technology is the possibility of operating the LED as a two-way converter - of electrical energy into light and of light into electrical energy [7, 8, 9, 10].

There are many experiments and studies that prove the possibility of using LEDs simultaneously as sources and as light sensors [14, 15], as well as receivers and transmitters in the so-called LiFi systems and VLC [13, 16]. The known publications do not reflect specific parameters and characteristics that can be used in possible future developments.

The purpose of this report is to present and describe an experimental setup and the resulting experimental studies of a bidirectional LED converter.

BRIEF THEORETICAL STATEMENT

A. LIGHT INTO ELECTRIC CURRENT

The search for the possibility of applying the standard discrete LED as a bidirectional LED converter begins with a description of the processes that occur in the pn junction during light emission and light absorption.

As is known, the absorption of electromagnetic radiation by semiconductors is carried out through the interaction of photons with current carriers or with the crystal lattice of the semiconductor crystal itself. As a result, several types of absorption can be distinguished - intrinsic absorption, in which the electron passes from a bound to a free state, but provided that the energy of the

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photons is greater than the width of the forbidden band of the irradiated semiconductor.

Another type is impurity absorption, in which ionization or excitation of the impurity centers in the semiconductor is caused, i.e. transition of an electron from a donor level to the conduction band or of an electron from the valence band to the acceptor level, but when irradiated with a certain wavelength.

Light absorption by free carriers is due to the acceleration of electrons by the electric field. This acceleration is obtained from the energy of the electromagnetic wave of the electric field. The absorption of light during its interaction with the oscillating atomic charges of the crystal lattice has a resonant nature, in which only the transverse optical photons of the light wave participate. Exciton absorption is the coupling of an electron with a hole. This forms an exciton, which can move freely in the crystal lattice, carry energy, but cannot carry charge and be accelerated by the electric field.

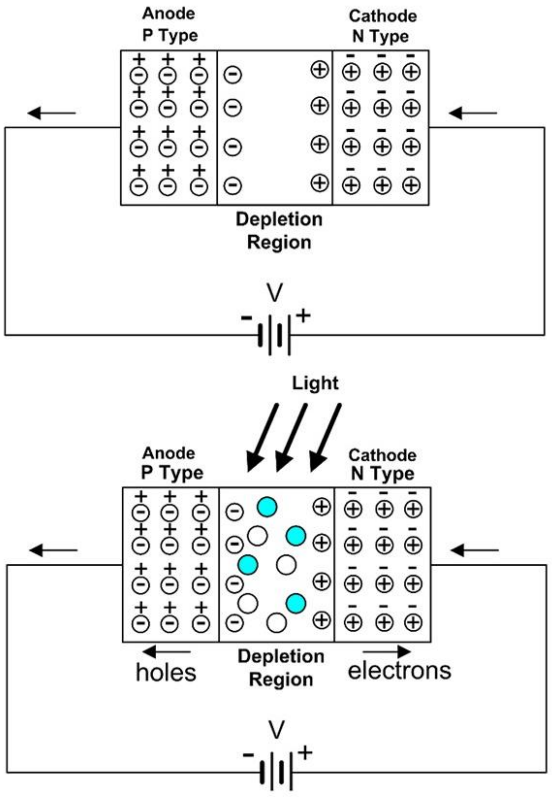


Fig. 1. *Operation of the pn-junction as a Photodiode [17]*

When the pn-junction (photodiode) is illuminated, photoionization occurs (Fig. 1). It is characterized by the formation of electron and hole pairs. They disrupt the balance between the diffuse and drift currents of the current carriers through the junction. A photocurrent is generated.

The current-voltage characteristic of the photodiode can be described by the following equation:

$$I = I_S(e^{\frac{U}{m.\varphi_T}} - 1) - I_\Phi, \quad (1)$$

where: I_S – saturation current, m – emission coefficient, φ_T – temperature potential, I_Φ – photocurrent. For the total current through the photodiode, the following equation is valid:

$$I = -(I_S + I_\Phi) \quad (2)$$

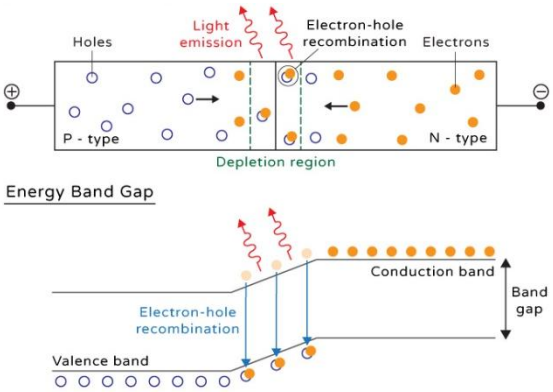


Fig. 2. *Light emitting diode operation [18]*

B. ELECTRIC CURRENT IN LIGHT. It is known that the flow of electric current in the forward direction is accompanied by recombination of the injected minority carriers. This, in turn, is accompanied by the release of energy. In one case, the energy is in the form of light (quanta or photons) (Fig. 2), and in the other case it is heat and causes an increase in the thermal oscillations of the crystal lattice.

EXPERIMENTAL SETUP

The schematic of the experimental setup is shown in Fig. 3.

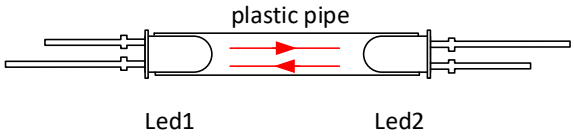


Fig. 3. *Experimental setup diagram*

Fig. 4 presents an experimental setup, through which the research was conducted. It consists of a breadboard, two identical LEDs, type C503B-WAN-CCaDb151, emitting white light, and an opaque cylinder. The latter has an internal hole made along the entire length with a diameter of Φ=5mm, as well as the diameter of the housings of the LEDs used. The measuring instruments and the power supply source are connected through the connecting wires, as shown in Fig. 5.

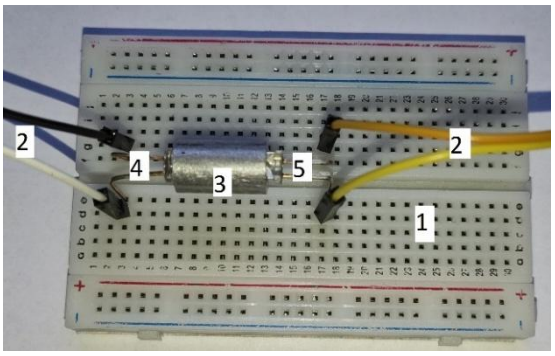
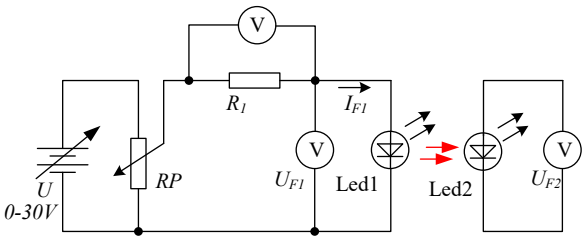


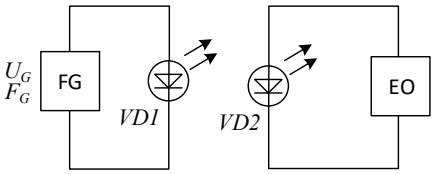
Fig. 4. *Experimental setup: 1-Breadboard, 2-connecting wires, 3-opaque cylinder, 4-Led1, 5 – Led2*

To conduct the experiment, two LEDs Led1 and Led2, an opaque plastic or metal tube with an internal diameter equal to the diameter of the LEDs (in this case, φ=5mm were used) and a length l=20mm are required. The LEDs are mounted on both sides of the tube as shown in Fig. 4. The two LEDs are of the same type.

The electrical circuits shown in Fig. 5 are used to conduct experimental studies.



a)



b)

Fig. 5. *Electrical diagram of the experimental setup*

It is necessary to note that the experimental studies are real and not simulations, and the schemes shown in Fig. 5 are implemented with real measuring instruments.

EXPERIMENTAL RESULTS

The experimental studies were carried out under conditions of room temperature (T_O=25°C) and humidity. The LEDs included in the experimental setup are type C503B-WAN-CCaDb151. In order to prove their uniformity, their volt-ampere characteristics I_F=f(U_F) were experimentally recorded, using the circuit in Fig.5a. By means of a stabilized adjustable power source, a supply voltage is supplied to the LEDs in the range from 0 to 3V. This is achieved with the potentiometer *RP*, and the voltage on the LED U_F is measured with a voltmeter connected in parallel to it. The current through the LED I_F is measured in a voltmeter as a voltage drop across the resistor R_1. In this way, the error of the measuring instrument is reduced.

The analysis of the obtained results shows that the obtained experimental characteristics I_F=f(U_F), Fig. 6, are typical for this type of electronic components. It was also found that the selected LEDs Led 1 and Led 2 have very close parameters, since their volt-ampere characteristics coincide, Fig. 6.

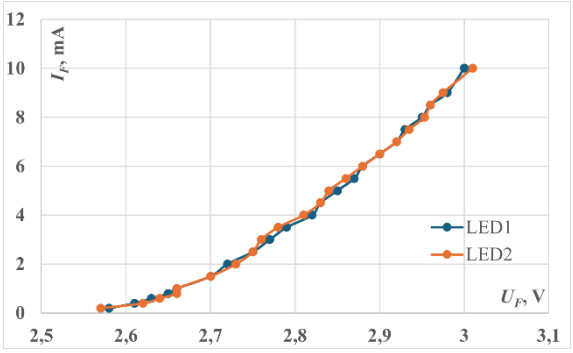


Fig. 6. *Experimental characteristics*

$I_F=f(U_F)$

From the data obtained for the characteristics $I_F=f(U_F)$, the differential static resistance of the LEDs was determined by the following formula:

$$r_S = \frac{\Delta U_F}{\Delta I_F}, \quad (3)$$

where: ΔU_F and ΔI_F are respectively the change in the current passing through the LED, corresponding to the change in the voltage drop across it.

It was found that r_S is almost constant for the entire studied range of change in the supply voltage U_F. A higher value of the static resistance is observed (r_S = 0,1Ω) at lower current values (I_F = 0,4 ÷ 0,8 mA), while it decreases (r_S = 0,03Ω) with increasing current (I_F = 8 ÷ 9 mA). This is a natural phenomenon because at a lower electric field the resistance of the diffusion is higher due to the smaller number of current carriers passing through the junction.

Of interest are the characteristics reflecting the dependence of the generated voltage U_{F2} by the LED Led 2, operating as a photodetector, on the current I_{F1} passing through the LED Led 1, which emits light (Fig. 5a) – $U_{F2}=f(I_{F1})$. They are shown in Fig. 7.

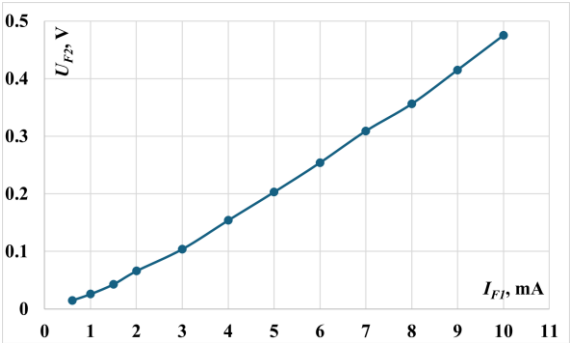


Fig. 7. *Experimental transient response characteristic $U_{F2}=f(I_{F1})$*

The analysis of the obtained characteristic $U_{F2}=f(I_{F1})$ shows a linear change in the generated voltage U_{F2}, from the LED Led2, with increasing current IF1 through the LED Led1, i.e. with increasing luminous flux.

The voltage transmission coefficient A_U can be determined from the following simple formula:

$$A_U = \frac{U_{F2}}{U_{F1}} \quad (4)$$

Using equation (4), the dependence $A_U=f(I_{F1})$ was constructed, reflecting the change in A_U from the voltage of U_{F1} on Led 1 – Fig. 8.

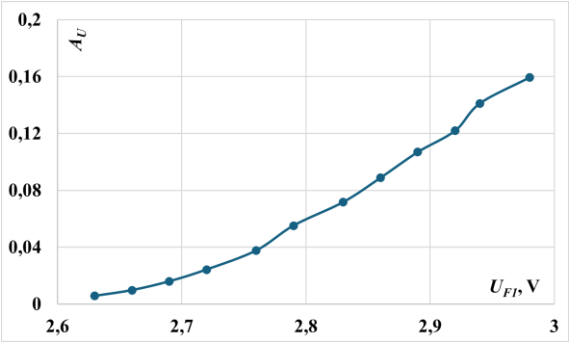


Fig. 8. *Dependence of the voltage transmission coefficient on the input voltage $A_U=f(U_{F1})$*

As can be seen from the graph (Fig. 8) A_U increases with an almost linear character. It is established that the characteristic has a slope from 0,012 to 0,018. The results are understandable, considering that the LEDs used have a lens that causes internal reflection and scattering of both the emitted and received light.

The characteristic $U_{F2}=f(U_{F1})$ presented in Fig. 9 also proves the uniformity of the LEDs used, and its character reflects the loss of light when passing through the optics of the LEDs.

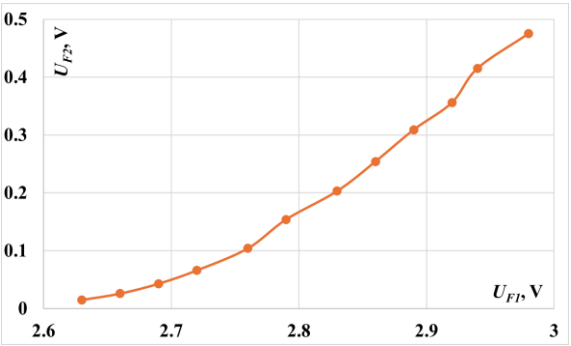


Fig. 9. *Experimental transmission characteristic $U_{F2}=f(U_{F1})$*

CONCLUSION

The continuous growth of the need for sensor elements for the conversion of various non-electrical quantities necessitates the search and creation of new sensor mechanisms.

The presented real experimental studies show the possibility of one and the same LED working as a transmitter and as a receiver of light energy.

The conducted experimental studies also prove the possibility of using a standard discrete LED as a two-way energy converter - electrical to light and vice versa.

The captured experimental characteristics allow detailed modeling and creation of new experimental setups, allowing for more extensive theoretical and experimental research of LEDs.

The presented scheme of the experimental setup, as well as the experimental electrical measurement schemes, can be directly used for further research and development.

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