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TRANSDUCERS OF OPTICAL POWER ON THE BASIS OF FIELD-EFFECT PHOTOTRANSISTORS WITH BILATERAL ILLUMINATION OF CHANNEL

The paper considers the opportunity of transformation of optical power on the basis of the autogenerating device which consists of transistor structures with negative resistance, and where IG- field-effect transistor structure with bilateral illumination of channel is photosensitive element. Analytical dependences of volt - ampere characteristic and transformation function, which can be used for engineering calculation of parameters of optical power converters, are obtained.

***Key words**: MOS-phototransistor, optical radiation, complete resistance, transistor structures with negative resistance, mathematical model.*

INTRODUCTION

Modern state-of-art of information-measuring engineering is determined by the trend to dynamic introduction of high-performance miniature primary transducers of physical quantities in control and diagnostics systems of technical and nontechnical processes in military sphere, aerospace industry, automobile industry and other branches of modern economy of Ukraine.

Present situation stipulates the necessity of carrying out research in industry of home production of microelectronic transducers of physical quantities aimed at improvement of their basic parameters: efficient weight-dimension indexes, high reliability, sensitivity, stability of characteristics, accuracy, reproducibility, low cost, wide nomenclature and integration with microprocessor devices of the measured information processing [1 – 3].

Structural association of integral primary measuring transducers with the digital microprocessor devices allows to carry out their intellectualization. Besides reading of the measured information its practically simultaneous processing, filtration, compression and correction is performed. Thus advantage of using of frequency information signal of primary transducer over its analog form as voltage or current is conditioned by simplicity and accuracy of frequency conversion in digital code, its high interference immunity while transmission and efficiency of commutation in multichannel measuring systems [3]. The use of reactive properties of transistor structures with negative resistance for creation of generating devices and functional microelectronic transducers with the frequency information coding is perspective direction [4].

For the study of such transducers properties the mathematical model of phototransducer on the basis of microelectronic frequency transducers of optical power is required . Therefore the task was to develop the mathematical model on the base of which it is possible to obtain-voltage current characteristic, dependence of complete resistance of structure, deduce the conversion function.

Mathematical model

Having analyzed the available transducers of optical power on the basis of the use of reactive properties of semiconductor structures [5], the authors of the paper suggested their own method aimed at solution of problems in this field of sensor engineering , namely to use radio metering circuitry on the basis of field-effect transistor structure with bilateral illumination of channel.

Field-effect phototransistor is developed for the solution of applied tasks of integral photoelectronics and photosensing technology.

There exist metal-oxide-semiconductor field-effect phototransistors (MOSFEPT) with semitransparent electrode across which an under-gate region is illuminated . It is also known , that the gate electrode of thin-film MOSFEPT can be made non-transparent, and illumination can be done through the substrate. A low photosensitivity and complicated technology refers to the drawbacks of such devices [6]. In the known phototransistor on the basis of MOS-structure, which contains semiconductor substrate, one of surfaces of which is sensitive to the radiation, with the regions of drain, source and channel, where dielectric layer and gate electrode are formed , the surface of substrate is free of dielectric and is sensitive to radiation and has slots above the region of the channel [7].

In order to expand functional abilities (namely: increase sensitivity of phototransistor to radiation), in the offered construction MOSFEPT, that contains substrate with *p-Si*, with transparent gate electrode made of Au, across which the under-gate region is illuminated, from the back side of substrate under the region of the channel deep slots are made, sectional area of each of which corresponds to the following relation: $A < S/n$, where S is the area of the channel, n – is a number of slots. Thus the depth of slots must satisfy the condition: $ad \to 1$, where a – is coefficient of absorption, d is thickness of plate between the bottom of the slot and gate dielectrics (Fig. 1). Thus illumination is performed across the substrate and the gate.

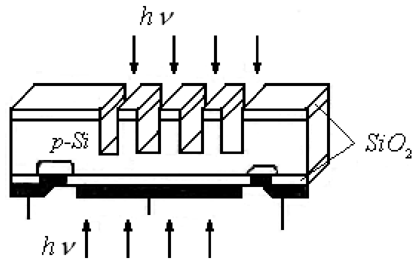

Fig. 1. Construction of MOSFEPT with bilateral illumination of channel

The diagram of frequency transducer on the basis of bipolar one and MOS-transistor is shown in Fig. 2. MOS-transistor with bilateral illumination of channel is photosensitive element.

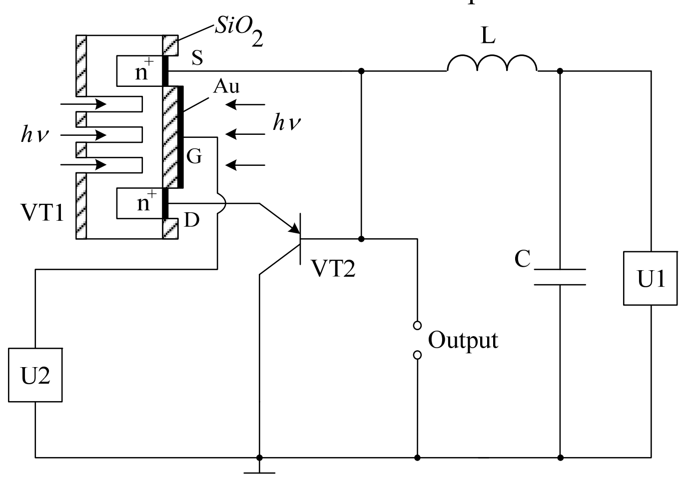

Fig. 2. The electric circuit of transducer on the basis of MOSFEPT and bipolar transistor

For the calculation of-voltage current characteristic (VCC) of transduser on the basis of its equivalent circuit for direct current (Fig. 3) we will take advantage of the Kirchhoff's equation system (1). For the VCC definition it is expedient to choose the method of contour currents, and it was done. The advantage of this method is that it visually enables to define VCC, in terms of the developed theory of matrix calculations.

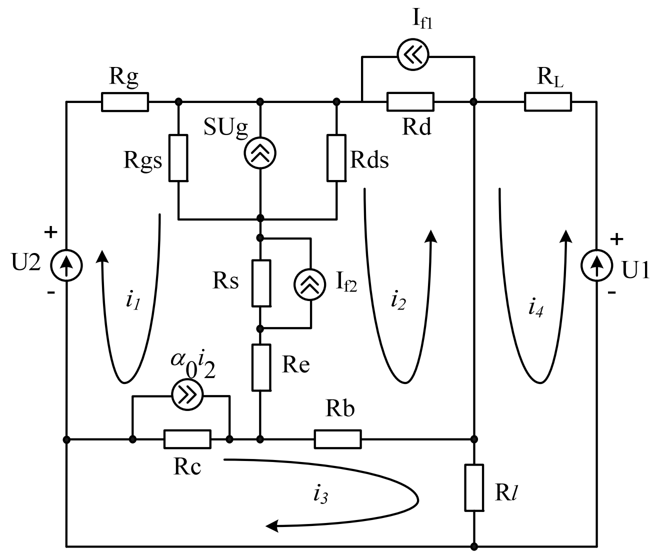

Fig. 3. Equivalent circuit of transducer for direct current

$$\begin{cases} U_1 = (R_l + R_L)i_4 + R_l i_3, \\ 0 = (R_c + R_b + R_l)i_3 - R_c\alpha_0 i_2 + R_b i_2 + R_l i_4, \\ 0 = (R_b + R_d + R_{ds} + R_s + R_e)i_2 + R_b i_3 + \\ + R_s I_{f2} + (R_s + R_e)i_1 - R_d I_{f1} + R_{ds} SU_g, \\ U_2 = (R_g + R_{gs} + R_s + R_e + R_c)i_1 + R_{gs} \cdot SU_g + \\ + (R_s + R_e)i_2 + R_s I_{f2} - R_c i_3 + R_c \alpha_0 i_2. \end{cases} \quad (1)$$

Having solved the system of equations (1) by means of programme package MatLab 5.2, we will define the VCC of frequency transducer (Fig. 4). Obviously, the greater power of light radiation is, the higher the VCC maximum lies.

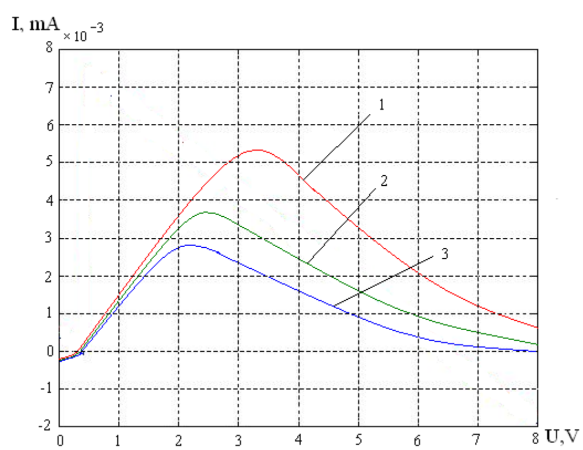

Fig. 4. Set of the VCC of microelectronic frequency transducer of optical power:

$1 - 120\ \mu Watt/cm^2$; $2 - 60\ \mu Watt/cm^2$; $3 - 0\ \mu Watt/cm^2$

For determination of the conversion function it is necessary to define the dependence of oscillation frequency on power of incident radiation. It is possible to perform by solving the system of Kirchhoff's equations , which is composed for alternating current on the basis of equivalent circuit (Fig. 5).

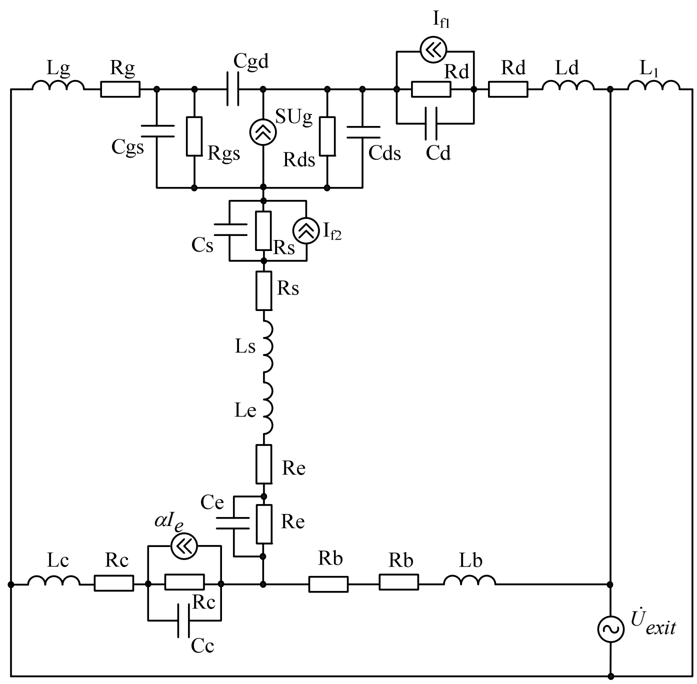

Fig. 5. Equivalent circuit of transducer on the basis of bipolar transistor and MOSFEPT

For convenience of calculations equivalent circuit is shown in Fig. 6.

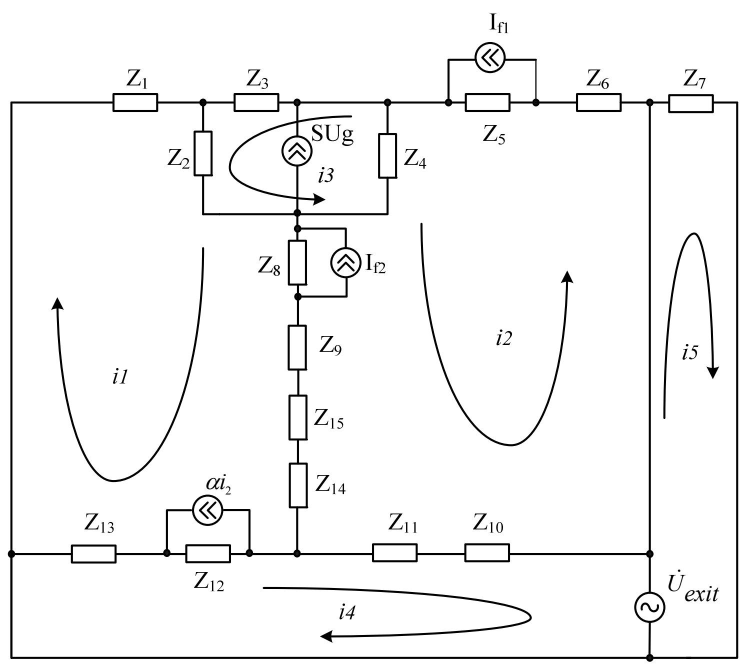

Fig. 6. The modified equivalent circuit of transducer

The Kirchhoff's equations system for alternating current is:

$$
\begin{cases}
\dot{U}_{exit} = Z_7 i_5, \\
\dot{U}_{exit} = \left(Z_{13} + Z_{12} + Z_{11} + Z_{10}\right) i_4 + Z_{12}\alpha i_2 - (Z_{13} + Z_{12}) i_1 + (Z_{10} + Z_{11}) i_2, \\
0 = \left(Z_4 + Z_8 + Z_9 + Z_{15} + Z_{14} + Z_{11} + Z_{10} + Z_6 + Z_5\right) i_2 + Z_8 I_{f2} + \\
+(Z_8 + Z_9 + Z_{14} + Z_{15}) i_1 + \left(Z_{10} + Z_{11}\right) i_4 + Z_4 S U_g - Z_4 i_3 - Z_5 I_{f1}, \\
0 = \left(Z_1 + Z_2 + Z_8 + Z_9 + Z_{15} + Z_{14} + Z_{12} + Z_{13}\right) i_1 + Z_2 i_3 + Z_2 S U_g + Z_8 I_{f2} + \\
(Z_8 + Z_9 + Z_{15} + Z_{14}) i_2 - Z_{12}\alpha i_2 - (Z_{12} + Z_{13}) i_4, \\
0 = \left(Z_3 + Z_2 + Z_4\right) i_3 + Z_2 i_1 + (Z_3 + Z_2 - Z_4) S U_g - Z_4 i_2.
\end{cases}
\tag{2}
$$

where

$$Z_1 = R'_g + j\omega L_g,\ Z_2 = \frac{R_{gs}}{1+\omega^2 R_{gs}^2 C_{gs}^2} - j\frac{\omega R_{gs}^2 C_{gs}}{1+\omega^2 R_{gs}^2 C_{gs}^2},\ Z_3 = -j/\left(\omega C_{gd}\right),\ Z_7 = j\omega L_1,$$

$$Z_6 = R'_d + j\omega L_d,\ Z_4 = \frac{R_{ds}}{1+\omega^2 R_{ds}^2 C_{ds}^2} - j\frac{\omega R_{ds}^2 C_{ds}}{1+\omega^2 R_{ds}^2 C_{ds}^2},\ Z_9 = R'_s + j\omega L_s,\ Z_{11} = R_b,$$

$$Z_{10} = R'_b + j\omega L_b,\ Z_5 = \frac{R_d}{1+\omega^2 R_d^2 C_d^2} - j\frac{\omega R_d^2 C_d}{1+\omega^2 R_d^2 C_d^2},\ Z_{13} = R'_c + j\omega L_c,\ \alpha = \alpha_1 - j\alpha_2,$$

$$Z_{15} = R'_e + j\omega L_e,\ Z_8 = \frac{R_s}{1+\omega^2 R_s^2 C_s^2} - j\frac{\omega R_s^2 C_s}{1+\omega^2 R_s^2 C_s^2},\ \alpha_1 = \frac{\alpha_0}{1+\left(f/f_\alpha\right)^2},\ \alpha_2 = \frac{\alpha_0 f/f_\alpha}{1+\left(f/f_\alpha\right)^2},$$

$$Z_{12} = \frac{R_c}{1+\omega^2 R_c^2 C_c^2} - j\frac{\omega R_c^2 C_c}{1+\omega^2 R_c^2 C_c^2},\ Z_{14} = \frac{R_e}{1+\omega^2 R_e^2 C_e^2} - j\frac{\omega R_e^2 C_e}{1+\omega^2 R_e^2 C_e^2},$$

where R'_b, R'_c, R'_e is resistance of base, collector and emitter terminals accordingly; R_b, R_c, R_e is the volume resistance of base, collector, emitter accordingly; C_c, C_e is capacity of collector and emitter junctions; L_b, L_c, L_e is inductance of base, collector and emitter electrodes; R'_g, R'_d, R'_s is the resistance of gate, drain and source terminals accordingly; L_g, L_d, L_s is inductance of gate, drain and source terminals accordingly; L_1 is external inductance; R_d, R_s is the volume resistance of drain, source; I_f is the value of photocurrent of drain and source *p-n*-junctions; C_d, C_s is capacity of drain and source *p-n*-junctions; R_{gs}, R_{ds} is resistance gate-source, drain-source; C_{gs}, C_{gd}, C_{ds} is capacity gate-source, gate-drain, drain-source; f is an operating frequency; f_α is critical frequency of bipolar transistor in a common-base circuit. The numerical values of these parameters are taken hereof [8].

Having solved the system of equations (2) with the help of programming package MatLab 5.2, we will determine the value of complete resistance on the collector-drain electrodes of the transducer. An active component of impedance takes a negative value, and reactive component of impedance takes the capacity character. Connection of external inductance to the collector-gate terminals of structure at the negative values of active component, when the losses of energy are compensated in an oscillating circuit allows to create the signal oscillator. At action of light on the channel of MOSFEPT the change of active and reactive component of resistance is carried out, and this in its turn, changes oscillation frequency.

If we separate complete resistance into actual and imaginary components, we will define the equivalent capacity of oscillating circuit, which depends on power of optical radiation. The equivalent capacity of transducer determines dependence of oscillation frequency on power of operating light. In this case the conversion function looks like

$$F_0 = \frac{1}{2\pi R_{eq}(P) C_{eq}(P)} \sqrt{\frac{R_{eq}^2(P) C_{eq}(P)}{L} - 1}.$$

Fig. 7 shows dependence of oscillation frequency on power of optical radiation.

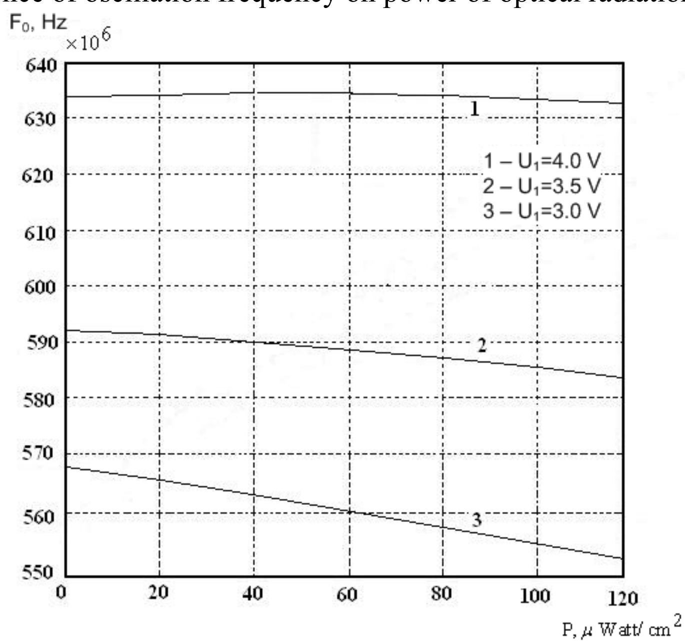

Fig. 7. Dependence of resonance frequency on power of optical radiation

Changing supply mode of photosensitive transducer, it is possible to obtain linear dependence of oscillation frequency on the power of incident light.

Phototransducers with frequency output on the basis of transistor structures with negative differential resistance are used for realization of new technical solutions at the solution in problems of emission-spectral control effectiveness increase [9]

Other measuring circuits , built on the basis of MOS-structure and active oscillator are possible. The authors of the article obtained a number of patents on the inventions and useful models.

Conclusion

Mathematical model of microelectronic transducer of optical power, which consists of bipolar transistor and MOS-structure with bilateral illumination of channel is developed. On the basis of mathematical model-voltage current characteristic and conversion function are obtained.

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