UDC 621.3.049

Y. Kravchenko, Cand. Sc. (Eng.), Assist. Prof.; O. Danilenko, Post-Graduate

MATHEMATICAL MODEL OF THE EMISSION-SPECTRAL FREQUENCY CONVERTER

The paper presents the mathematical model for microelectronic converter of the intensity of optical radiation in frequency. The converter is used for systems of the emission-spectral control for plasmachemical processes. Mathematical simulation of voltage-current characteristic and the conversion function in the form of relation of generation frequency from optical power has been performed.

***Keywords**: mathematical model, structures of transistors with negative resistance, emission-spectral control.*

Introduction

The operative control of parameters of technological processes and, in particular, the control of processes of plasma etching is the important condition for providing automation of these processes. One of the most informative and technological methods of plasma processes control is rather popular method of emission spectroscopy. This method is based on registration of optical spectrum of own radiation of excited atoms and molecules in plasma. However, there is a problem of low responsivity of photo converters in circuits of emission-spectral control, especially at small values of intensity of plasma own radiation. It reduces accuracy of measurement of the moment of etching process completion and limits quantity of excited components of plasma with insignificant intensity of the spectrum of own radiation. The control of small intensity of plasma radiation is achieved due to its transformation into frequency. It is achieved with the help of semiconductor devices with negative differential resistance in circuits of photo converters [1, 2].

The research of properties of such converters needs the mathematical model of the photo converter based on application of microelectronic frequency converters taking into account spectral composition of nonequilibrium plasma radiation. Therefore the problem involves the elaboration development of mathematical model to obtain dependence of active and reactive component of full resistance of the structure, to define the function of transformation.

Mathematical model

The circuit of the frequency converter with bipolar and mosfet transistors is shown in Fig. 1. The photosensitive element of the circuit is the photo resistor. Its spectral characteristic satisfies spectrum of plasma radiation for plasmachemical etching.

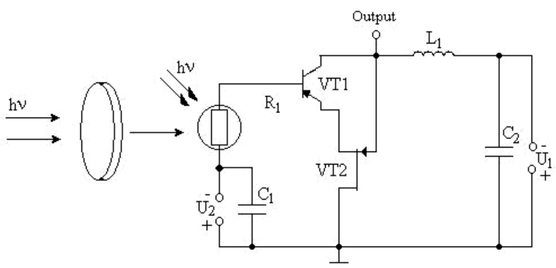

Fig. 1. The circuit of the emission-spectral converter with the photo resistor

For calculation of current-voltage characteristic of the converter based on its equivalent circuit for direct current (Fig. 2) [3] we shall take a set of Kirchhoff equations (1).

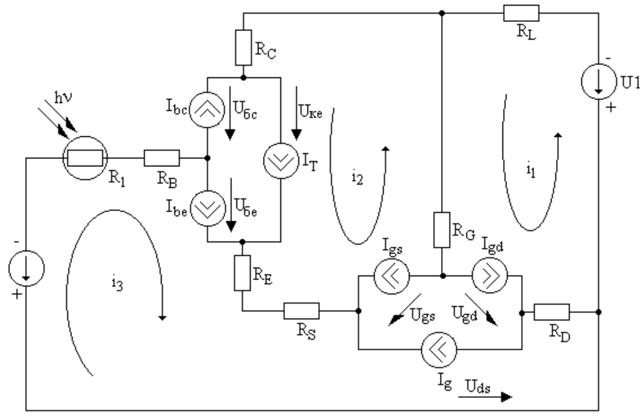

Fig. 2. The equivalent circuit of the converter for direct current

$$
\begin{cases}
U1=(R_L + R_G + R_D)(i_1 + I_{gd} + I_g - I_{gs}) - R_G(i_2 - I_{gs} - I_T - I_{bc} + I_g + I_{gd})+ \\
+ R_D(i_3 - I_g + I_{gs} - I_{gd} - I_{be} + I_{bc} + I_T), \\
0=(R_C + R_E + R_S + R_G)(i_2 + I_g - I_{gs} + I_{gd} + I_{be} - I_{bc} - I_T) - R_G(i_1 + I_{gd} + I_g - I_{gs})+ \\
+ R_E(i_3 - I_g + I_{gs} - I_{gd} - I_{be} + I_{bc} + I_T)+ R_S(i_3 - I_g + I_{gs} - I_{gd} - I_{be} + I_{bc} + I_T), \\
U2=(R1 + R_B + R_E+ R_D)(i_3 - I_g + I_{gs} - I_{gd} - I_{be} + I_{bc} + I_T)+ \\
+ R_D(i_1 + I_{gd} + I_g - I_{gs}) + R_E(i_2 + I_g - I_{gs} + I_{gd} + I_{be} - I_{bc} - I_T) + \\
+ R_S(i_2 + I_g - I_{gs} + I_{gd} + I_{be} - I_{bc} - I_T).
\end{cases}
\tag{1}
$$

The solution of the set of Kirchhoff equations (eqn.1) by means of software Matlab 5.2 , gives current-voltage characteristic of the frequency converter (Fig. 3) [3].

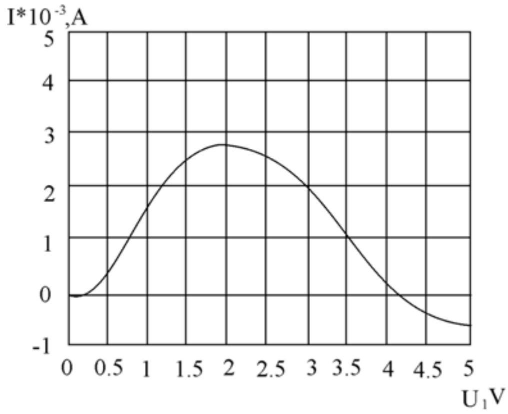

Fig. 3. Current-voltage characteristic of the emission-spectral converter with the photo resistor

To define the transfer function of the photo converter it is necessary to calculate full resistance for a collector - drain electrodes of transistors VT 1 and VT 2 according to its equivalent circuits for alternating current (Fig. 4) [3].

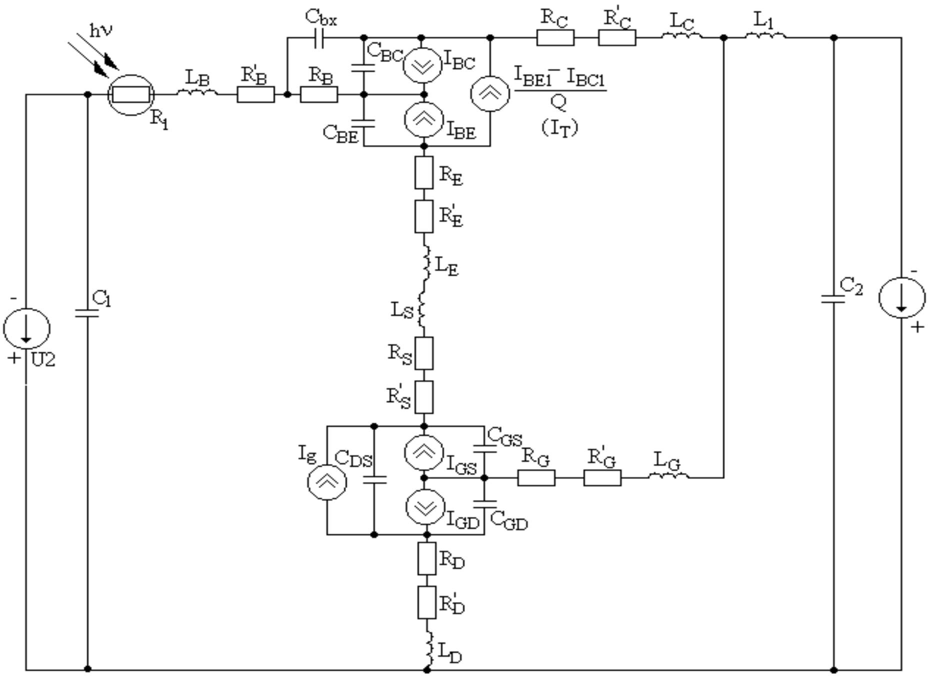

Fig. 4. The equivalent circuit of the emission-spectral converter with the photo resistor

The set of Kirchhoff equations for an alternating current is following [3]:

$$
\begin{aligned}
&U_1 = Z_{16}(i_1 + i_2),\\
&0 = (Z_8 + Z_{16} + Z_{15} + Z_{13} + Z_{14})i_2 + Z_{16}i_1 + Z_{14}i_3 + Z_{13}i_7 - Z_{15}i_4 +\\
&+ Z_{13}(I_{gd} - I_{gs} - I_g),\\
&0 = (Z_7 + Z_6 + Z_4 + Z_9 + Z_{10} + Z_{12} + Z_{14})i_3 - Z_6 i_6 + Z_6(-I_{bc} + I_{be} + I_T) +\\
&+ Z_4 i_4 + Z_4(-I_{bc} + I_{be} + I_T) + (Z_9 + Z_{10})i_4 - Z_{12}i_7 + Z_{12}(-I_{gd} + I_{gs} + I_g) + Z_{14}i_2,\\
&0 = (Z_1 + Z_2 + Z_3 + Z_4 + Z_9 + Z_{10} + Z_{11} + Z_{15} + Z_{17})i_4 + Z_4(-I_{bc} + I_{be} + I_T) +\\
&+ (Z_9 + Z_{10})i_3 + Z_{11}i_7 + Z_{11}(-I_{gd} + I_{gs} + I_g) + Z_3 i_6 + Z_4 i_3 - Z_{15}i_2 - Z_{15}i_5,\\
&U_2 = Z_{17}(i_5 - i_4),\\
&0 = (Z_5 + Z_3 + Z_6)i_6 + Z_3 i_4 - Z_6 i_3 + Z_6(I_{bc} - I_{be} - I_T),\\
&0 = (Z_{11} + Z_{13} + Z_{12})i_7 + Z_{11}i_4 + Z_{11}(-I_{gd} + I_{gs} + I_g) - Z_{12}i_3 + Z_{12}(I_{gd} - I_{gs} - I_g) +\\
&+ Z_{13}i_2 + Z_3(I_{gd} - I_{gs} - I_g),
\end{aligned}
\tag{2}
$$

where,

$$
\begin{array}{lll}
Z_1 = R_1, & Z_2 = R'_B + j\omega L_B, & Z_3 = R_B,\\
Z_5 = -j/(\omega C_{bx}), & Z_6 = -j/(\omega C_{BC}), & Z_{17} = -j/(\omega C_1),\\
Z_{11} = -j/(\omega C_{DS}), & Z_{12} = -j/(\omega C_{GS}), & Z_{13} = -j/(\omega C_{GD}),\\
Z_7 = R_C + R'_C + j\omega L_C, & Z_9 = R_E + R'_E + j\omega L_E, & Z_{10} = R_S + R'_S + j\omega L_S,\\
Z_{14} = R_G + R'_G + j\omega L_G, & Z_{15} = R_D + R'_D + j\omega L_D, & Z_4 = -j/(\omega C_{BE}),\\
 & Z_{16} = -j/(\omega C_2), & Z_8 = j\omega L_1.
\end{array}
$$

where, R'_B, R'_C, R'_E - resistance of base, collector and the emitter accordingly; R_B, R_C, R_E - volumetric resistance of base, collector and emitter accordingly; C_{BC}, C_{BE} - capacity of base - collector junction and base - emitter accordingly; C_{bx} - capacity between the base and collector; L_B, L_C, L_E - inductance of base, collector and emitter; Q - charge in base; R_G, R_D, R_S - volumetric resistance of the gate, drain and the source accordingly; $R_G^{'}, R_D^{'}, R_S^{'}$ - resistance of the drain, gate and source accordingly; C_{DS}, C_{GD}, C_{GS} - capacity of source - drain, gate-drain, gate-source accordingly; L_G, L_D, L_S - inductance of the source, drain and gate lead accordingly; $L1$ - external inductance.

Having solved of the set of equations (eqn.2) by means of software Matlab 5.2 we can obtain the value of full resistance on electrodes of collector - drain converter. The equivalent capacity of oscillatory circuit has been found by dividing full resistance into the valid and imaginary part. This capacity depends on power of incident light. Fig. 5 [3] shows the theoretical dependence of active component on consumption voltage.

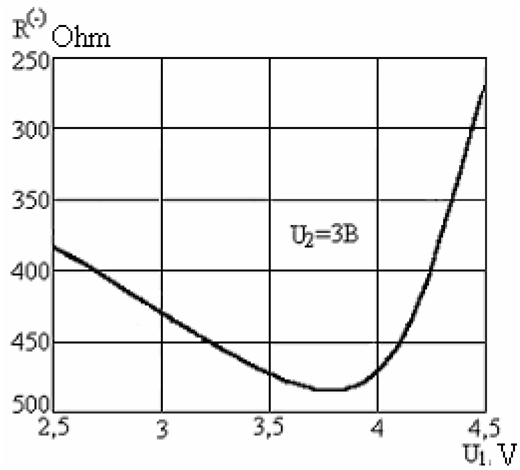

Fig. 5. Theoretical dependence of active component on voltage supplied voltage

Fig. 6 shows calculated dependence of full resistance reactive component on radiation power.

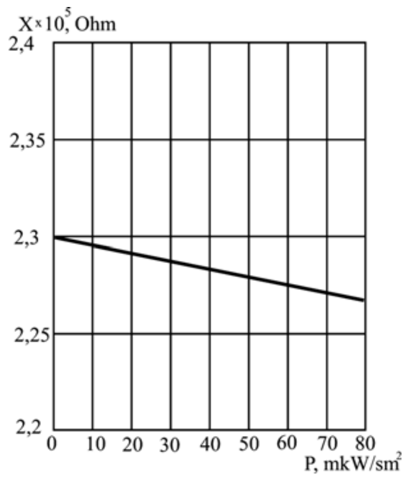

Fig. 6. Theoretical dependence of reactive component on variation of optic radiation power

It is necessary to find dependence of generation frequency on power of optical radiation for definition of transfer function [3]. It can be realized by solving the set of Kirchhoff equations (2) for an alternative current. Transfer function of is [3]:

$$F = \frac{1}{4}\frac{\sqrt{2}\sqrt{\dfrac{R_1^2(P)C_f^2 + C_{GD}R_1^2(P)C_f - LC_{GD} - A}{LC_{GD}R_1^2(P)C_f^2}}}{\pi}, \quad (3)$$

where $A = \sqrt{\left(R_1^2(P)C_f^2 + C_{GD}R_1^2(P)C_f - LC_{GD}\right)^2 + 4LC_{GD}R_1^2(P)C_f^2}$.

Dependence of generation frequency on power of incident light is shown in Fig. 6 [3].

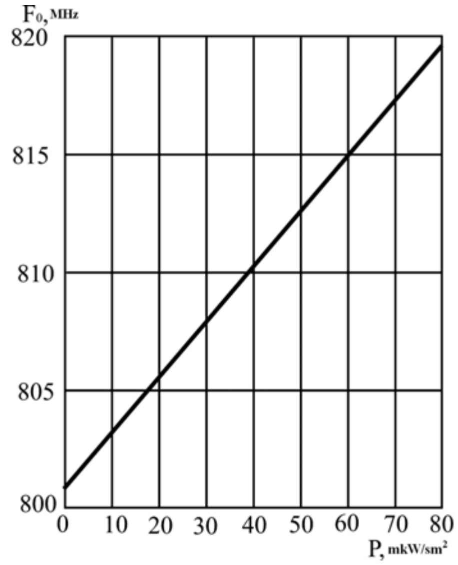

Fig. 7. Dependence of generation frequency on power of optical radiation

Conclusion

The mathematical model of emission-spectral frequency converter composed for bipolar, mosfet transistors and a photosensitive element - the photoresistor has been developed. The I-V characteristic and transfer function have been found for this model.

REFERENCES

1. The patent of Ukraine № 4229, H01L 21/302. The device for definition of the moment of the ending of process of plasma etching / Kravchenko J.S., Danilenko O.O. // L. № 1 - 2005.

2. The patent of Ukraine № 4413, H01L 21/302. The device for definition of the moment of the ending of process of plasma etching / Kravchenko J.S., Danilenko O.O. // V. № 1 - 2005.

3. Osadchuk O.V. Microelectronic frequency converters on the basis of transistor structures with negative resistance. - Vinnitsa, 2000, p.303.

Yuriyy Kravchenko – Assistant Professor of the Department;

Olena Danilenko – Post-Graduate student of the Department.

The Department for Electronics, Vinnytsia National Technical University