Osadchuk A.V.

Doctor of Technical Sciences, Professor, Head of Radioengineering Department Vinnitsa National Technical Universit, Vinnitsa, Ukraine

Osadchuk V.S.

Doctor of Technical Sciences, Professor, Prof. of Radioengineering Department, Vinnitsa National Technical University, Vinnitsa, Ukraine

Osadchuk I.A.

PhD, Researcher of Radioengineering Department Vinnitsa National Technical University, Vinnitsa, Ukraine

GAS CONCENTRATION TRANSDUCERS WITH FREQUENCY OUTPUT SIGNAL BASED ON REACTIVE PROPERTIES OF SEMICONDUCTOR STRUCTURES WITH NEGATIVE DIFFERENTIAL RESISTANCE

Abstract: The paper presents the results of studies on the creation of frequency microelectronic transducers of gas concentration based on autogenerator transistor devices. In the proposed devices, the gas concentration is converted into a frequency output signal. Such a conversion allows to remote all disadvantages of analog gas sensors: low output voltage, low sensitivity, parasitic influence of measuring channels on each other, instability in operation, need for amplifying devices and analog-digital transducers by subsequent processing of measurable information.

The paper considers the mechanism of formation of the impedance of semiconductor gas sensors, in which the active component is determined by the surface resistance, and the reactive component is determined by the surface capacitance. The dependence of the magnitude of the impedance on changes in the concentration of active gases characterizes the essence of the gas-reactive effect of the sensors, which unambiguously changes the output frequency of autogenerating gas transducers.

Schemes of frequency microelectronic transducers of gas concentration based on transistor structures with negative resistance are proposed and studied. In the falling section of the current-voltage characteristics, the operating point of the device is selected, which ensures the self-excitation of the transducer self-oscillator. The energy losses in the oscillatory circuit of the autogenerator are replenished by negative resistance. A method for calculating current-voltage characteristics, output impedance, transformation functions, and sensitivity of devices are proposed. The calculations are based on mathematical models of transducers, which follow from the Kirchhoff equations. Equations are compiled on the basis of nonlinear equivalent circuits of frequency devices. The microelectronic frequency transducer of gas concentration works in the oscillation mode of the oscillator because of proper selecting a constant voltage of the power supply. The conversion functions and the sensitivity equations of an autogenerating gas transducer have been determined, with the device sensitivity ranging from 300 ppm to 1000 ppm being 270 Hz/ppm, and ranging from 1000 ppm to 5000 ppm – 120 Hz/ppm.

Keywords: autogenerating gas transducer, gas-reactive effect, reactive properties of semiconductors, impedance, frequency output signal, negative resistance.

Introduction

The characteristics of the transducers determine the accuracy and reliability of control and regulation systems for process monitoring devices, environmental characteristics, industrial plant safety, etc. Therefore, gas converters are subject to stringent requirements. They should be economic, provide high accuracy of measurement, have minimum dimensions, weight and energy consumption, be compatible with modern computers and have the ability to manufacture on standard integrated technology [1-4].

Currently, the existing semiconductor gas sensors do not meet the above requirements. They have a low output signal, low accuracy and sensitivity, require analog-to-digital converters and amplifiers for further signal processing. A promising scientific direction, which allows to eliminate the disadvantages of existing analog gas sensors, is the creation of converters that implement the principle of transformation "gas concentration – frequency" on the basis of autogenerator semiconductor structures with negative differential resistance.

Development of autogenerator gas transducers with a frequency output signal requires knowledge of changes in the impedance of primary semiconductor gas transducers from changes in gas concentration, that is, the gas reactive effect, because these processes cause changes in the parameters of the oscillating circuit of autogenerators, which in turn determines the dependence of the output frequency of devices [5-8]. Thus, the work is devoted to the study of the mathematical model of the gas reactive effect in semiconductor gas sensors, that is, the dependence of their total output resistance on the gas concentration, which is determined by the processes on the surface of the semiconductor.

Theoretical and experimental research

The gas reactive effect is understood as the dependence of the total resistance of semiconductor primary analogue gas-sensitive sensors on the change of measured gases. The change of the active component of total resistance leads to the change of the negative differential resistance, and the change of the reactive component changes the capacity of the oscillating circuit of autogenerator gas transducers, which eventually leads to a unique dependence of the output frequency of autogenerator devices from the change of concentration of measured gases. Semiconductor analog gas sensors have a number of drawbacks, such as low output signal, low accuracy and sensitivity, the need for amplifier devices and analog-to-digital converters in further signal processing, the parasitic effect of one measurement channel on another channel, which can be eliminated by using the method of converting the physical quantity to the frequency [2, 7, 8]. When using the frequency conversion method, it is necessary to know the dependence of the impedance of the primary analogue semiconductor gas sensors on the action of measured gases and the effect of this effect on the output frequency of autogenerator gas transducers.

Physical processes occurring on the surface of semiconductor gas-sensitive sensors when they interact with measured gases are described by the Poisson equation. This equation describes the distribution of electrostatic potential in a spatial charge layer in a near-surface layer of a semiconductor. A sample of a semiconductor of a gas-sensing element in normal conditions must be electrically neutral. Where it follows that the surface charge Q_p must be compensated equal and opposite to the sign of the charge in the near-surface layer of the semiconductor. This charge shields the volume of the semiconductor from penetration into it of an electric field and consists of semiconductor located in the volume of ionized donor and acceptors and mobile electrons and holes. Thus, the surface layer of the semiconductor is a layer of spatial charge that shields the volume of the semiconductor from the electric field of the surface charge, and this shielding is carried out due to the fact that the equilibrium concentration of electrons and holes in the layer differs from the bulk. A more complete and precise solution of the Poisson equation is made in the work of Garrett and Brattain, the translation of which is made in the monograph [9]. In this paper, we consider a general case of a semiconductor that is under the influence of excitatory factors such as illumination, radiation. In the future we will proceed from the most widespread version of the calculations, which is presented in the monograph of A.V. Rzhanov [10].

Determine the complete near-surface resistance of a Z_S semiconductor gas-sensing sensor in general form, assuming that it represents a parallel connection of the near-surface C_S capacitance and the active surface-to-ground resistance R_S

$$Z_S = \frac{R_S}{1+(\omega C_S R_S)^2} + \frac{R_S{}^2 \omega C_S}{1+(\omega C_S R_S)^2}, \tag{1}$$

where ω – circular frequency. Surface-specific (ohm/cm^2) active resistance in the general case has the form [10]

$$R_S = [q\mu_{ns} n_s(y_s,\gamma,\alpha) + q\mu_{ps} p_s(y_s,\gamma,\alpha)]^{-1}, \tag{2}$$

where q is the charge of the electron, μ_{ns}, μ_{ps} – the mobility of the electrons and holes, n_s, p_s – the over-shock of electrons and holes in the near-surface layer of the semiconductor, y_s – the surface of the three-dimensional electrostatic potential, γ – the dimensionless coefficient characterizing the volumetric properties of the gas sensor semiconductor, α – the dimensionless coefficient characterizing the degree of violation of the thermodynamic equilibrium in the semiconductor. The concentration of excess electrons and holes is described by expression [10]

$$n_S(y_S,\gamma,\alpha) = \frac{1}{2} n_0(\gamma^{-1}+\alpha) L_D \int_{y_S}^{0} \frac{(e^y - 1)}{f(y,\gamma,\alpha)} dy, \tag{3}$$

$$p_S(y_S,\gamma,\alpha)=\frac{1}{2}p_0(\gamma+\alpha)L_D\int_{y_s}^{0}\frac{(e^{-y}-1)}{f(y,\gamma,\alpha)}dy, \tag{4}$$

where n_0, p_0 – the equilibrium concentration of electrons and holes in the volume of the semiconductor, y – the dimensionless electrostatic potential, the function $f(y,\gamma,\alpha)$ has the form [10]

$$f(y,\gamma,\alpha)=\mp\left[(\gamma+\alpha)(e^{-y}-1)+(\gamma^{-1}+\alpha)(e^{y}-1)+(\gamma-\gamma^{-1})y\right]^{\frac{1}{2}}, \tag{5}$$

$$L_D=\left(\frac{\varepsilon\varepsilon_0 kT}{2\pi q^2 n_i}\right)^{\frac{1}{2}}, \tag{6}$$

where $\varepsilon, \varepsilon_0$ – the dielectric constants of semiconductor and vacuum, k – Boltzmann's constant, n_i – are the concentration of electrons in their own semiconductor, L_D – the distance of electric field penetration into their own semiconductor, T – the absolute temperature. It should be noted that in formula (5) the negative sign in front of the square bracket corresponds to the positive sign, and the positive sign - to the negative value of the dimensionless electrostatic potential. Substitution of expressions (3) and (4) in equation (2) describes the specific resistance of the semiconductor gas sensor

$$R_S(y_S,\gamma,\alpha)=\left[\frac{1}{2}qn_i\mu_{ps}L_D\int_{y_s}^{0}\frac{(\gamma+\alpha)(e^{-y}-1)+b_s(\gamma^{-1}+\alpha)(e^{y}-1)}{f(y,\gamma,\alpha)}dy\right]^{-1}, \tag{7}$$

where $b_s=\mu_{ns}/\mu_{ps}$ – the ratio of electron mobility to hole mobility. Integral in expression (7) does not have a decoupling in analytical form and should be calculated numerically, but at a significant value of the surface potential for the electron semiconductor the integral takes on an approximate value, and the specific near-surface resistance looks like

$$R_{sn}=\left[q\mu_{ns}n_0L_D(\gamma^{-1}+\alpha)^{\frac{1}{2}}e^{\frac{1}{2}y_s(w)}\right]^{-1}, \tag{8}$$

and for a hole semiconductor at significant negative values of the surface potential y_s the near-surface active resistivity is described by

$$R_{sp}=\left[q\mu_{ps}p_0L_D(\gamma+\alpha)^{\frac{1}{2}}e^{-\frac{1}{2}y_s(w)}\right]^{-1}, \tag{9}$$

where w – the concentration of active gases on the sensor. The analysis of dependence of near-surface active resistivity on surface potential for electronic semiconductor shows that at significant positive values y_s, when there is a large excess of electrons in the near-surface layer of enrichment, this excess of electrons will determine near-surface resistivity, exponentially depends on the index, which is equal to half of the value y_s. At decrease y_s at first the growth of near-surface resistance according to this law is observed. In the area of small positive values y_s of active resistance growth it slows down, because the charge of the spatial charge layer is becoming increasingly important for the charge of ionized donors.

Let's move on to the determination of specific capacity (pF/cm^2) of the near-surface layer of the spatial charge of the semiconductor gas sensor. The connection between the charge and the potential is nonlinear, which determines the differential capacity of the spatial charge layer. From the solution of the Poisson equation and the general determination of the capacity, we obtain the value of the specific capacity of the spatial charge [10]

$$C_{пр.зар} = \frac{q^2 n_i L_D \left[(\gamma^{-1} + \alpha) e^{y_s(w)} - (\gamma + \alpha) e^{-y_s(w)} + (\gamma - \gamma^{-1}) \right]}{2kTf(y_s(w), \gamma, \alpha)}. \qquad (10)$$

For an own semiconductor, when $\gamma = 1$ and $\alpha = 0$, the expression (10) is much simpler

$$C_{sp.ch} = \frac{1}{2} \frac{q^2 n_i L_D \left[e^{y_s(w)} - e^{-y_s(w)} \right]}{kT \left[\left(e^{y_s(w)} - e^{-y_s(w)} + 2 \right)^{\frac{1}{2}} \right]}. \qquad (11)$$

The analysis of the formula (11) shows that the differential capacity of the spatial charge takes the minimum value $y_s = 0$, when there is no bending of the energy zones.

Its value increases with both positive and negative values of the surface potential. At values $y_s \geq 3$ the differential capacity increases proportionally $\exp\left(\frac{1}{2} y_s \right)$. In the case of impurity samples of a gas sensor semiconductor, the dependence $C_{sp.ch}$ on the surface potential $y_s(w)$ is of a similar nature.

Substitution of formulas (8) and (11) for a semiconductor with an electronic type of gas sensor conductivity into expression (1) allows to get dependence of its total resistance on surface potential, which, in its turn, unambiguously depends on concentration of measured gases. The theoretical dependence of specific capacity and conductivity on the surface potential for various semiconductors with different types of conductivity are presented in [10]. The theoretical and experimental dependence of the output frequency on changes in the concentration of gases can be obtained on the basis of an autogenerator device, the scheme of which is presented in Fig. 1 [11, 12].

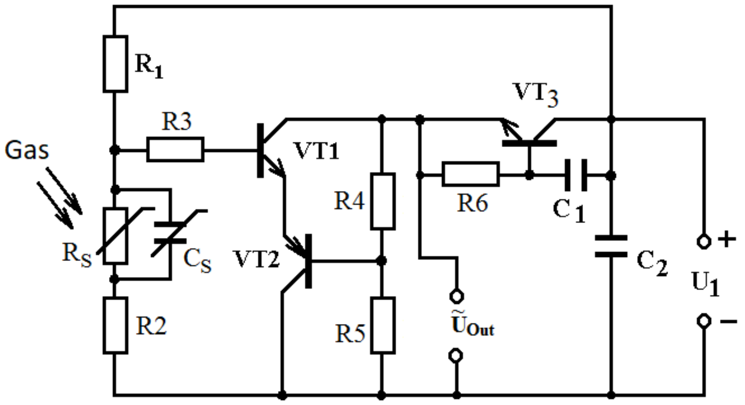

Figure 1. Electrical scheme of an autogenerator gas transducer based
on two bipolar transistors with an active inductive element

Creating a gas concentration transducer with a frequency output signal in the form of an integrated circuit requires the use of film technology for the manufacture of a passive inductive element in the form of a spiral, but its quality is of little importance and, secondly, its dimensions at frequencies up to 10^6 Hz are incompatible with the size of the integrated circuit transducer. Therefore, to solve this problem it was proposed to use the inductive nature of the total resistance of a bipolar transistor with a $RC-$ circuit, which is easily performed in the form of an integrated circuit [8]. Bipolar transistors $VT1$, $VT2$ and $VT3$ implement an autogenerator of electrical oscillations, in which the oscillating circuit is formed by the capacitive component of total resistance on the electrodes collector-collector of bipolar transistors $VT1$, $VT2$ and the inductive component of total resistance on the electrodes emitter-collector of bipolar transistor $VT3$.

On the electrodes of the collector-collector transistors $VT1$ and $VT2$ there is a negative differential resistance, which is realized on the falling section of the volt-ampere characteristic of the transducer. The volt-ampere characteristic itself is calculated on the basis of an equivalent device circuit from the Kirchhoff equation system. The falling section is in the range from 3V to 16V with the change of currents from 1mA to 8.5 mA. Negative differential resistance transforms the energy of the constant electric field into the energy of the alternating electric field, which allows to compensate the energy losses in the vibrating circuit of the transducer.

Conversion function, describes the dependence of the output frequency of the transducer on the change of gas concentration, is determined on the basis of nonlinear equivalent circuit of alternating current, based on the electrical scheme (Fig. 1). From the system of Kirchhoff equations, which are made on the basis of nonlinear equivalent circuit of the transducer by alternating current, the total output resistance on the electrodes of the collector-collector of transistors $VT1$ and $VT2$ is calculated. The system of Kirchhoff equations was solved with the help of Matlab 9.2 [13], which allowed to obtain the value of total output resistance, the active component of which has a negative value, and the reactive component has a capacitive character. From the equation, when the reactive component is equal to zero, we determine the dependence of the output frequency $F_0(w)$ of the transducer on the gas concentration, which looks like

$$F_0(w) = \frac{1}{2\pi R_g(w) C_{ekv}(w)} \left[\frac{R_g^2(w) C_{ekv}(w)}{L} - 1 \right]^{\frac{1}{2}}, \tag{12}$$

where $R_g(w)$ – the differential negative resistance of the oscillatory circuit, $C_{ekv}(w)$ is equivalent to the capacity of the oscillatory circuit, L – the value of the active inductance, w is the concentration of the measured gas. In fig. 2 the dependence of the output frequency of the autogenerator transducer on the change in the concentration of methane gas CH_4 is presented. The sensors of the firm Figaro (Japan) were sensors.

Sensitivity of the transducer is determined on the basis of expression (12) by differentiation of its argument w and is described by the formula

$$S_{F_0}^W = \frac{R_g(w) C_{ekv}(w) \frac{dR_g(w)}{dw} + R_g^2(w) \frac{dC_{ekv}(w)}{dw}}{4\pi R_g(w) C_{ekv}(w) L \left[\frac{R_g^2(w) C_{ekv}(w)}{L} - 1 \right]^{\frac{1}{2}}} - \frac{\left[\frac{R_g^2(w) C_{ekv}(w)}{L} - 1 \right]^{\frac{1}{2}} \frac{dR_g(w)}{dw}}{2\pi R_g^2(w) C_{ekv}(w)} - \frac{\left[\frac{R_g^2(w) C_{ekv}(w)}{L} - 1 \right]^{\frac{1}{2}} \frac{dC_{ekv}(w)}{dw}}{2\pi R_g(w) C_{ekv}^2(w)}. \tag{13}$$

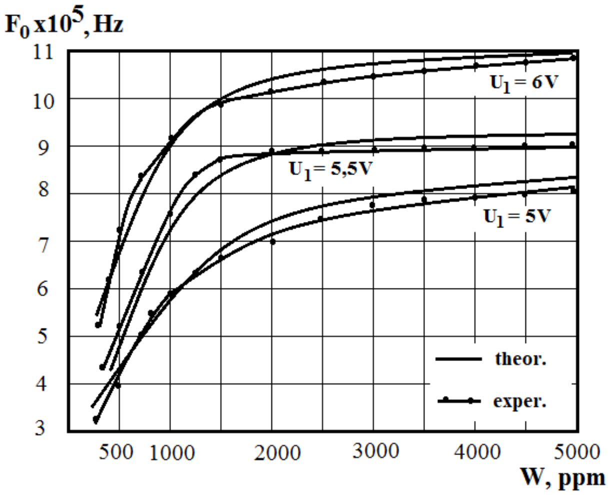

Figure 2. Theoretical and experimental dependence of the output frequency of the autogenerator transducer on methane concentration

Calculations showed that according to the formula (13), the sensitivity of the device was in the range from 300 ppm to 1000 ppm 270 Hz/ppm, and in the range from 1000 ppm to 5000 ppm – 120 Hz/ppm. The necessary parameter values for theoretical calculations were obtained from [14, 15].

The circuit of a microelectronic gas concentration sensor with a frequency output is shown in Figure 3. The proposed scheme of a microelectronic gas concentration sensor is built on a transistor structure of three bipolar transistors on a single crystal HFA3046. The scheme on electrodes of the collector-emitter of the bipolar transistor VT3 and the base-emitter of the bipolar transistor VT2 have a volt-ampere characteristic with a declining area corresponding to the appearance of a negative differential resistance. The operating point of the autogenerator from direct current is selected on the falling area of the volt-ampere characteristics.

The oscillating system of the autogenerator (Figure 3) consists of the capacitance existing on the collector-emitter VT3 electrodes, capacitance C1 as well as the external inductance L1. The resistances R1-R3 provide the mode of operation of transistors VT1, VT2 and VT3 from direct current.

The microelectronic gas concentration sensor operates as follows. The choice of a constant voltage source U1 is achieved by generating electrical oscillations of the auto generator. With the subsequent action of the gas concentration on the gas-sensitive resistor R2, its resistance changes, which results in the change in the equivalent capacity of the oscillatory circuit of the auto generator, which in turn changes the generation frequency.

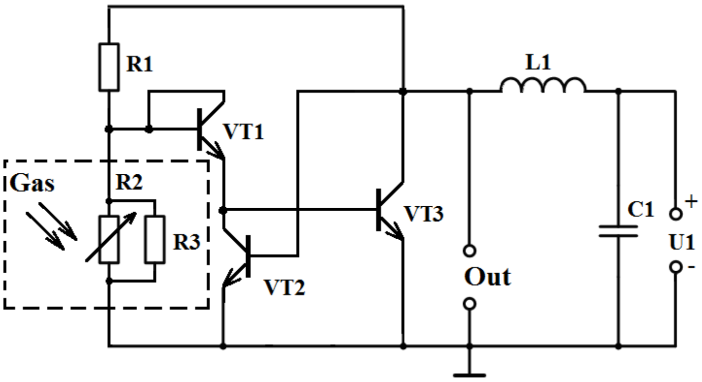

Figure 3. Electrical circuit of the gas sensor with frequency output

The resonant frequency, which depends on the change in gas concentration, is a sensor transformation function. It is determined on the basis of the zero reactive component of the complete input resistance of the circuit (Figure 2) and has the form

$$F(C)=\frac{1}{2\pi R_g C_{ekv}(C)}\left[\frac{R_g^2 C_{ekv}(C)}{L}-1\right]^{1/2}. \tag{14}$$

where R_g is differential resistance at the operating point of the circuit; R is loss of resistance in the oscillatory system; C_{ekv} is equivalent capacity of the oscillatory system; L is inductance of the oscillatory system.

The sensitivity of the frequency sensor of the gas is determined on the basis of expression (14) and is described by the equation

$$S_C^{F_p}=-\frac{1}{2}\frac{\sqrt{\frac{R_g^2 C_{ekv}(C)}{L}-1}\left(\frac{dC_{ekv}(C)}{dC}\right)}{\pi R_g^2 C_{ekv}(C)}+\frac{1}{2}\frac{\frac{dC_{ekv}(C)}{dC}}{\pi L\sqrt{\frac{R_g^2 C_{ekv}(C)}{L}-1}}. \tag{15}$$

In Figure 4, the transformation function is given, that is the dependence of the resonance frequency on the concentration of gas C_3H_8. As can be seen from the graph, the transformation function has a nonlinear character.

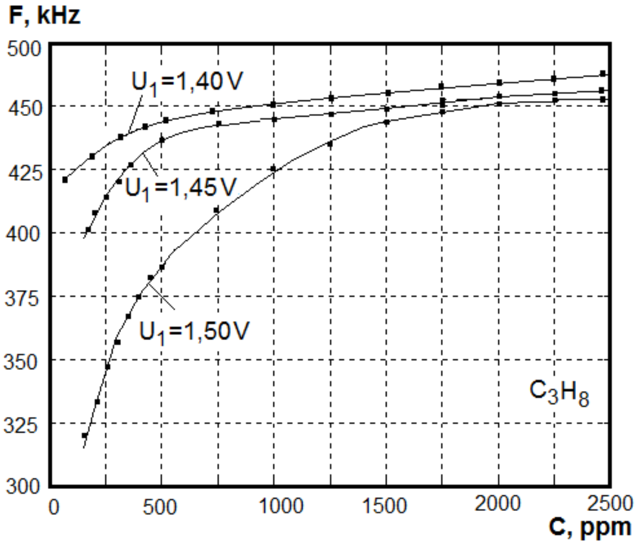

Figure 4. Dependence of the frequency of generations on the concentration of gas

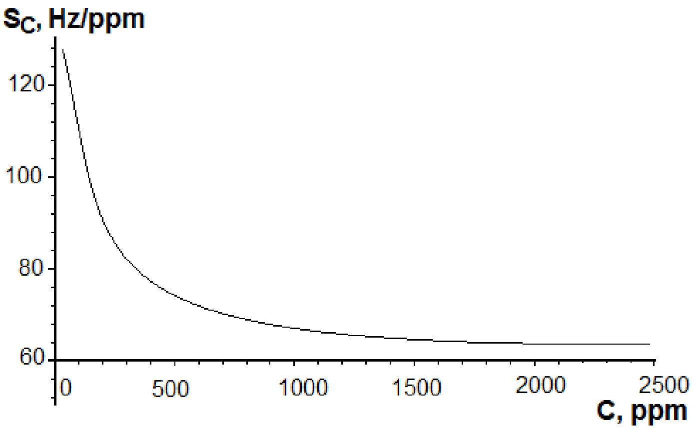

Figure 5. Dependence of sensitivity on gas concentration

Figure 5 presents the dependence of sensitivity of the sensor on the change in gas concentration. The analysis of the graph shows that the highest sensitivity of the device lies in the range of 100 ppm to 200 ppm and is 110 Hz/ppm, and in the range from 500 ppm to 1500 ppm is 65 Hz/ppm, the least sensitivity is 61 Hz/ppm in the range zone 1500 ppm to 2500 ppm.

The construction of the frequency transducer of gas concentration in the form of an integrated circuit requires the use of a film technology for the manufacture of a passive inductive element in the form of a spiral, but its quality factor is of little importance, and secondly, its dimensions at frequencies up to 10^6 Hz are incompatible with the dimensions of the integrated circuit of the transducer. Therefore, to solve this problem, it is suggested to use the inductive character of the impedance of a bipolar transistor with an RC circuit, which is easily implemented in the form of an integrated circuit [8]. Thus, the scheme of the frequency transducer of gas concentrations with an active inductive element is shown in Figure 6. Bipolar transistors VT1, VT2 and VT3 realize the electric oscillation generator in which the oscillatory circuit is formed by the capacitive component of the impedance at the collector-collector electrodes of the bipolar transistors VT1 and VT2 and the inductive component of the impedance at the electrodes of the emitter-collector of the bipolar transistor VT3. Thus, such a transducer circuit is fully realized in the form of an integrated circuit. The main parameters of the frequency transducer are the function of the conversion, that is, the dependence of the generation frequency on the change in the gas concentration and the equation of sensitivity.

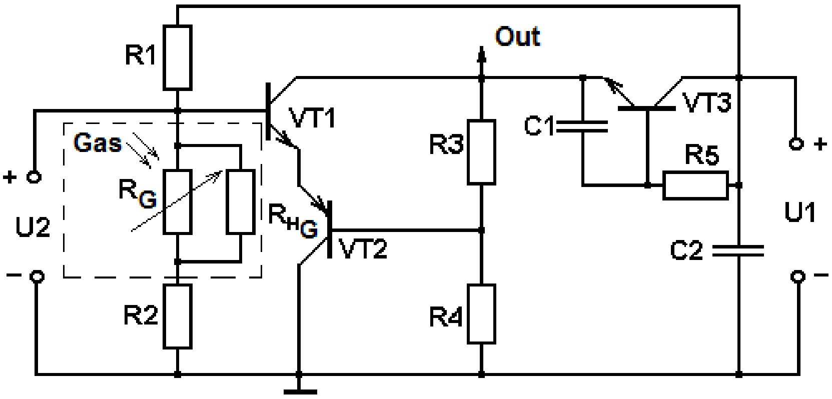

Figure 6. Electrical circuitry of the transducer on the basis of two bipolar transistors with active inductance

In Figure 7 the theoretical and experimental dependence of the active component on the supply voltage at different values of the control voltage is given. An increase in the supply voltage of more than 9 V (U_2 = 3.5V) leads to a lower dependence of the active resistance from U_1, and in the area from 9 V to 11 V has almost linear dependence.

Figure 8 shows the theoretical and experimental dependence of the reactive component of the impedance from the supply voltage. As it is seen from the graph that with increasing U_1 from 8.5 V to 12.5 V (U_2 = 4V), the reactive component increases to a greater extent than from 12.5 V to 14 V.

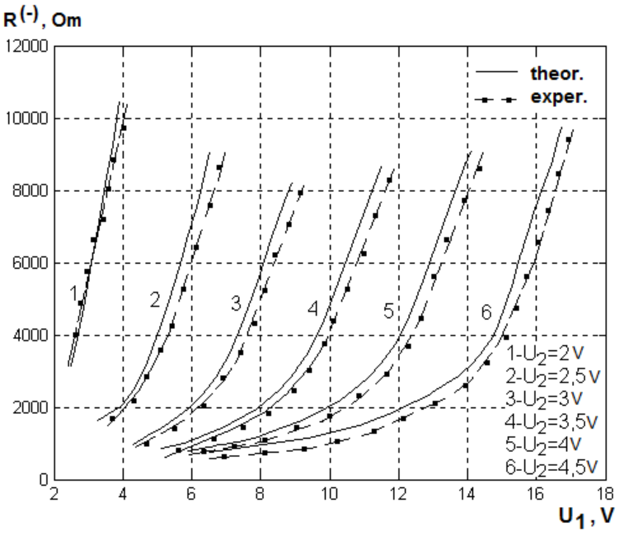

Figure 7. Theoretical and experimental dependence of the active component of the impedance of the supply voltage

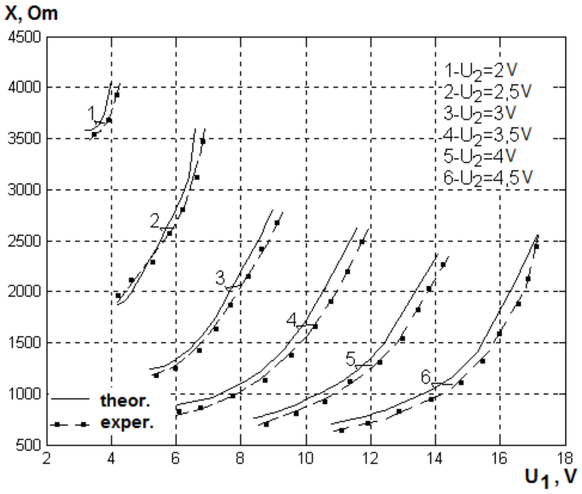

Figure 8. Theoretical and experimental dependence of the reactive component of the impedance from the supply voltage U_1

In Figure 9 the dependence of the generation frequency on the supply voltage at different voltage control is presented. From the graphs presented, it is seen that increasing control voltage increases the frequency region of generation. Experimental dependence of the generation frequency on the voltage of control at different voltage supply is shown in Figure 10. At a power supply of 5.5 V, the dependence is almost linear. Therefore, the 5.5V value for the supply voltage is optimal.

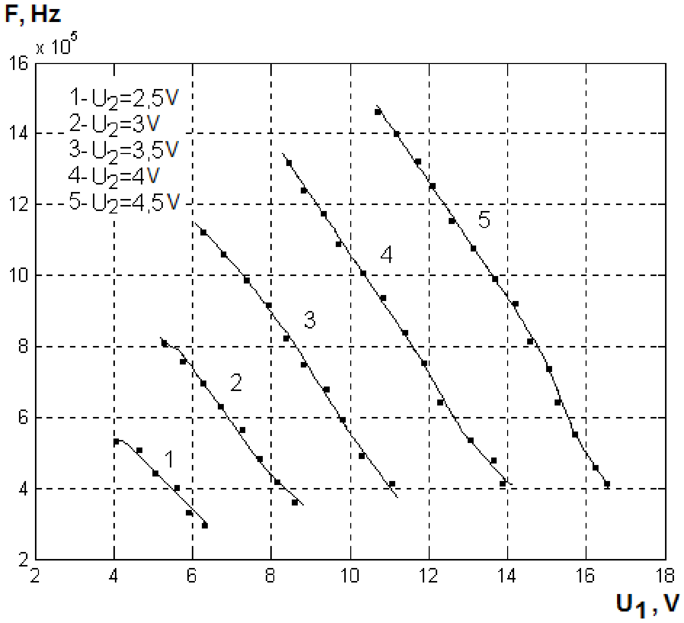

Figure 9. Experimental dependence of generation frequency on voltage U_1 at various voltage control

Figure 11 shows the dependence of the generation frequency on the concentration of gas. As you can see from the graph, the best dependence on the transformation function can be obtained if the supply voltage is equal to 5.5 V. As a gas sensitive element, the resistive sensor of the firm Figaro (Japan) was used.

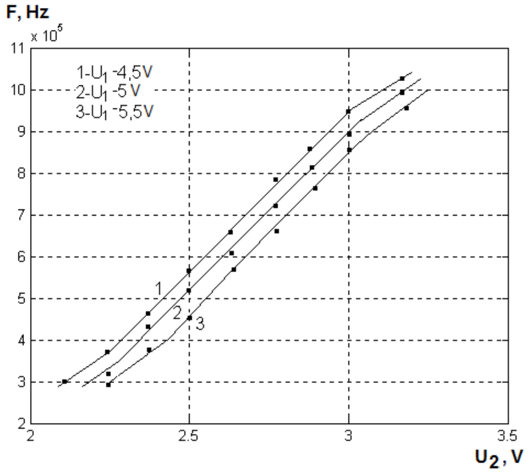

Figure 10. Experimental dependence of generation frequency on voltage of control U_2 at different power supply voltages

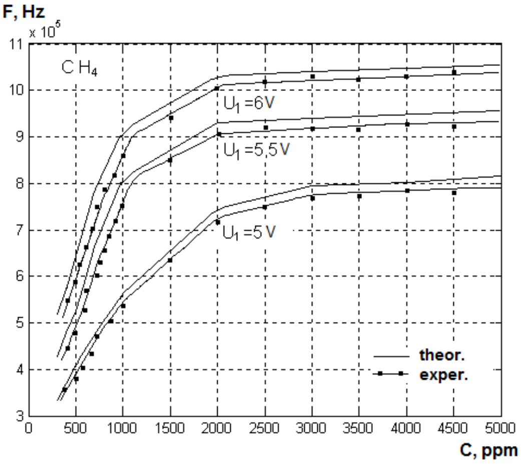

Figure 11. Theoretical and experimental dependence of the generation frequency on the concentrations of methane gas

Figure 12 and Figure 13 show the dependencies of the generation frequency on the propane gas concentrations, which were removed using sensors of the ACHE production type in Ukraine and the UST firm (Germany).

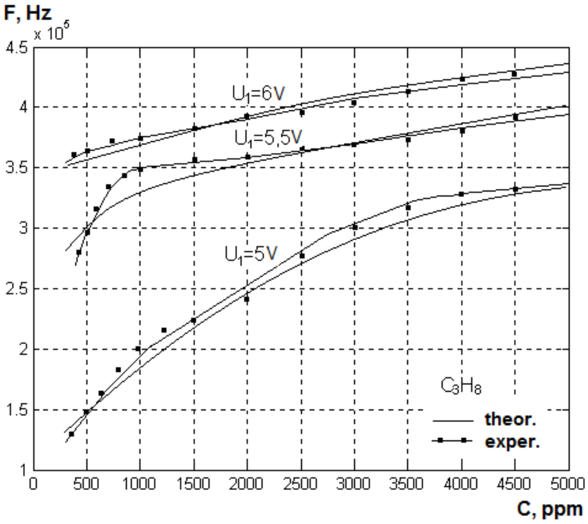

Figure 12. Theoretical and experimental dependences of the frequency of generations on the concentrations of propane (a sensitive element of the company ACHE, Ukraine) at different voltage levels

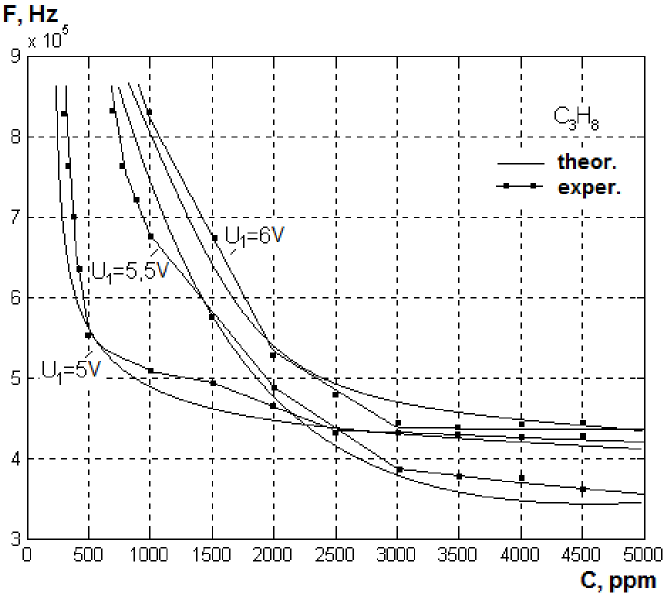

Figure 13. Theoretical and experimental dependences of the frequency of generations on the concentrations of propane (a sensory element of the firm UST, Germany) at different voltage levels

The dependence of the generation frequency on the gas concentrations is determined by the feedback loop according to the equivalent circuit. The transformation function is described by the expression

$$F=\frac{1}{2\pi}\sqrt{\frac{A_1+\sqrt{A_1^2+4R_5^2CC_{bx1}R_G(C)^2C_{HG}^2C_{bx2}\left(C_{bx1}+C_{bx2}\right)}}{2R_5^2CC_{bx1}R_G(C)^2C_{HG}^2C_{bx2}}}, \qquad (16)$$

where $A_1=R_G(C)^2C_{bx2}C_{HG}^2+R_5^2C_{HG}C_{bx1}C_{bx2}+C_{bx1}R_G(C)^2C_{HG}^2-R_5^2CC_{bx1}C_{bx2}$.

The sensitivity of the transducer is determined on the basis of expression (16) and is described by the equation

$$\begin{aligned}S_C^F=&\frac{1}{8}\sqrt{2}\Bigg(\Bigg(2C_{bx2}C_{HG}^2R_G(C)\left(\frac{\partial R_G(C)}{\partial C}\right)+2C_{bx1}C_{HG}^2R_G(C)\left(\frac{\partial R_{HG}(C)}{\partial C}\right)+\\&+\frac{1}{2}\Big(2B_1\times\Big(2C_{bx2}\,C_{HG}^2R_G(C)\left(\frac{\partial R_G(C)}{\partial C}\right)+2C_{bx1}\,C_{HG}^2R_G(C)\left(\frac{\partial R_G(C)}{\partial C}\right)\Bigg)\Bigg)+\\&+8B_2\times\left(\frac{\partial R_G(C)}{\partial C}\right)\Bigg)\Bigg)\Big/\sqrt{B_1+4B_2}\Big)/\left(R_5^2\,CC_{bx1}C_{bx2}C_{HG}^2\,R_G(C)^2\right)- \qquad (17)\\&-\frac{2B_1+\sqrt{B_1^2+4B_2}\left(\frac{\partial R_G(C)}{\partial C}\right)}{R_5^2CC_{bx1}C_{bx2}C_{HG}^2R_G(C)^3}\Bigg)\Bigg/\left(\pi\sqrt{\frac{B_1+\sqrt{B_1^2+4B_2}}{R_5^2CC_{bx1}C_{bx2}C_{HG}^2R_G(C)^2}}\right),\end{aligned}$$

where

$$B_1=R_G(C)^2C_{bx2}C_{HG}^2+R_5^2C_{HG}C_{bx1}C_{bx2}+C_{bx1}R_G(C)^2C_{HG}^2-R_5^2CC_{bx1}C_{bx2},$$

$$B_2=R_5^2(C_{bx1}+C_{bx2})C_{bx1}C_{bx2}C_{HG}^2CR_G(C)^2.$$

The graph of the sensitivity dependence on the concentration of gas is shown in Figure 14.

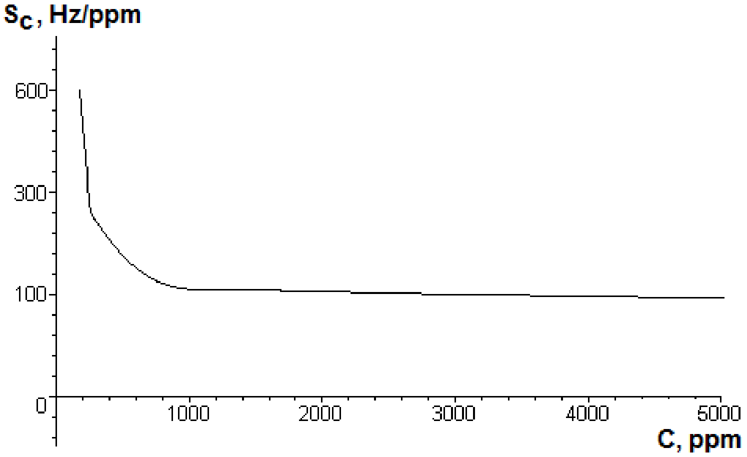

Figure 14. Dependence of sensitivity on gas concentration

According to the schedule, the highest sensitivity of the device ranges from 100 ppm to 300 ppm and has a value of 500 Hz/ppm, and at values of concentration from 300 ppm to 1000 ppm it assumes a value of 260 Hz/ppm. The range from 1000 ppm to 5000 ppm is 115 Hz/ppm.

CONCLUSION

The analysis of physical processes on the surface of semiconductor gas sensors has shown that in the formation of the subsurface layer of spatial charge there are excessive mobile charge carriers - electrons and holes, so the specific surface resistance is determined by their concentration, multiplied by the corresponding motility and elementary charge. On the other hand, the change of the charge in the layer of spatial charge at the change of the surface electrostatic potential is characterized by the introduction of the concept of differential capacity of the layer of spatial charge. Thus, the total resistance of semiconductor gas sensors consists of a parallel connection of the capacity of the surface layer of the spatial charge and near-surface resistance.

Change of total resistance of semiconductor gas transducers with frequency output signal from change of concentration of measured gases characterizes gas reactive effect of transducers, unequivocally changes output frequency of autogenerator gas transducers. The transformation functions and the sensitivity equation of the device were determined, with a sensitivity of 260 Hz/ppm in the range of 300 ppm to 1000 ppm, and in the range of 1000 ppm to 5000 ppm – 115 Hz/ppm..

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