It was shown that the semiconductor sensor characteristics can be sufficiently stable up to high fluences $10^{15}\div10^{18}$ n·cm^{-2}. This makes possible their application for the magnetic field measurement in accelerators and thermonuclear fusion facilities.

For magnetic field monitoring, the special magneto-measuring system with measuring channels accuracy of 0.01%, possessing self-control and self-correction functions was created.

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THERMOSENSITIVE INTEGRATED CIRCUITS WITH RELATIVE TEMPERATURE SCALE

On the basis of the received results of investigations new thermosensitive IC based on negative differential conductivity are created. These IC provide the possibility of temperature control in the wide temperature range of –50...+120^{0}C.

Thermometry is one of directions of development of devices and methods of measuring of thermal quantities. Measuring of temperature is connected with many directions of man's activity. The requirements to the methods of temperature measuring and temperature measuring devices raise all the time. Measuring devices, which provide higher accuracy, high speed, protection from the external influence are needed. Medicine, biology need creation of temperature measuring devices for a narrow range from a few Celsius degrees in a wide range (–50…+150^{o}C), with high speed, miniature sizes, with possibility of their introduction into the body or in a biological object.

The search of new methods and devices of temperature control is continued all the time. Lately temperature sensors, in which the functions of primary and secondary transducers are in single structural performance, were wider researched and developed. In these sensors (intelligent sensors) miniaturization and self-correction considering the changes of external factors, including changes of parameters of supply, are carried out. One of directions of realization of such sensors are single chip thermosensitive integrated circuits, which eliminate direct dependence of transduction function on the parameters of elements and allow to make devices without their individual calibrating. Range of temperature measuring of these IC is equal (-50...125)^{0}C, error of transduction function is equal (1...3)%. Interchangeability, simplicity of switching, small sizes, low cost are advantages of these IC. Such thermosensor devices are widely used in a domestic technique, biomedical electronics, apparatus of the ecological monitoring. The problems of their development , increase of accuracy, providing the given temperature range of measuring, principles of their structure are studying.

Analyzing modern development state one can show that research and elaboration of temperature sensors on the basis of integrated electronics is an actual task, the solving of which is needed for acceleration of scientific and technical progress in all directions of science, technique, medicine, ecology, etc.

Thermosensitive IC were one of the directions of our investigations. Nowadays there are thermosensitive IC with absolute temperature scale, output signal of which is proportional to the absolute temperature. But in some cases the signal that have information about an absolute temperature (for example, 300K, that corresponds to 27^{0}C) is not enough informational for measuring of 0,1^{0}C or 0,01^{0}C.

For example, in biology and medicine it is necessary to know the change of temperature of $0{,}1^0$C. · Output signal of such thermosensitive IC in this case changes on 0,03%, what cannot be registered with the help of known sensors of mass usage. For realization of this task it is necessary to use high accuracy secondary transducers. From another point of view, biomedicine needs mass sensors that are based on cheap, not so high accuracy temperature measuring transducers.

For the temperature control and registration in such narrow temperature range the principles of construction of thermosensitive IC with the scale of relative temperature (that is temperature relatively some reference temperature) were developed. In "classic thermometry" realization of procedure of relative temperature measuring is provided by bridge circuits.

However with transition on principles of transduction, that are used for construction of single chip thermosensitive IC, in particular, transduction on the basis of temperature dependence of direct p-n junctions or forming of signal with current scaling in the differentially connected transistors, the task of measuring of relative temperatures becomes more problematical. Essence of problem is in the forming of reference voltage U_0, which at substraction from initial voltage of transducer U_T forms the scale of relative temperature. Obviously, the temperature drift of reference voltage and nonlinearity of such drift causes additional component of instability of transduction function of thermometer.

Lately stabilitron was the most widespread element of reference voltage forming. Corresponding structural-technological decisions and compulsory selection allow to provide the high temperature stability of serial stabilitrons. However usage of stabilitron is connected with the following problem: impossibility of supply of IC from the low voltage supply sources. Minimum voltage of avalanche hasp of p-n junctions is limited by voltage of (6- 7) V, and for normal work of IC, for example IS LM 3911, supply voltage of order 15 V (with consecutively connected to the supply source current forming resistors) is necessary. Avalanche hasp is characterized by considerable level of noises, that also worsens the characteristics of thermosensitive IC with stabilitrons.

Stabilizers based on principle of synthesis of voltage equal to silicon forbidden gap width of $U_0 \approx 1{,}2$ V are the alternative solution of problem of reference voltage forming. Such stabilizers are characterized by high stability, minimum energy consumption and they are widely used in modern electronic apparatus.

Thus, realization of reference voltage source, which in modern stabilizers is formed on the principle of synthesis of voltage, equal to the width of the semiconductor forbidden gap, is necessary at elaboration of thermosensitive IC with relative temperature scale.

Unlike thermosensitive IC with absolute temperature scale, error of transduction of IC with relative temperature scale is determined by the parameters of unit of primary transducer and unit of stabilization of reference voltage. Minimization of resulting error of transduction of such IC requires the complex analysis of all destabilizing factors.

Thermosensitive IC with relative temperature scale that provide high stability and linearity of transduction function, extended functional possibilities, minimum energy consumption and possibility of the normal functioning with the low voltage one polar supply sources are developed . Such thermosensitive IC with relative temperature scale unlike IC with absolute temperature scale, without complicated structure, with minimum supply voltage and minimum sizes allow measuring of $0{,}1^0$C in a narrow temperature region (from 1^0C and more) in the range of $-50...+120^0$C.

We investigated that for typical Early voltage, which is equal approximately 50V, there is negative differential conductivity. Negative differential conductivity is caused by the change of currents of base circuits and modulation of transistor input characteristic by collector voltage. On the basis of the revealed negative differential conductivity in the circuits of current stabilization the functional stabilizer with maximally high stability at the change of supply voltage was developed [1]. The original electrical circuits of primary transducer consist: functional stabilizer – former of current I_T on elements T_1–T_4, R_E, R_Z, current mirror - divider on T_5-T_7 and elements of relative temperature scale forming D, R_T, R_L, R_0.

The unit of primary transducer with relative temperature scale forms a current of linear dependence on absolute temperature, which is transduced into differential signal the value of which is determined by the scale of relative temperature.

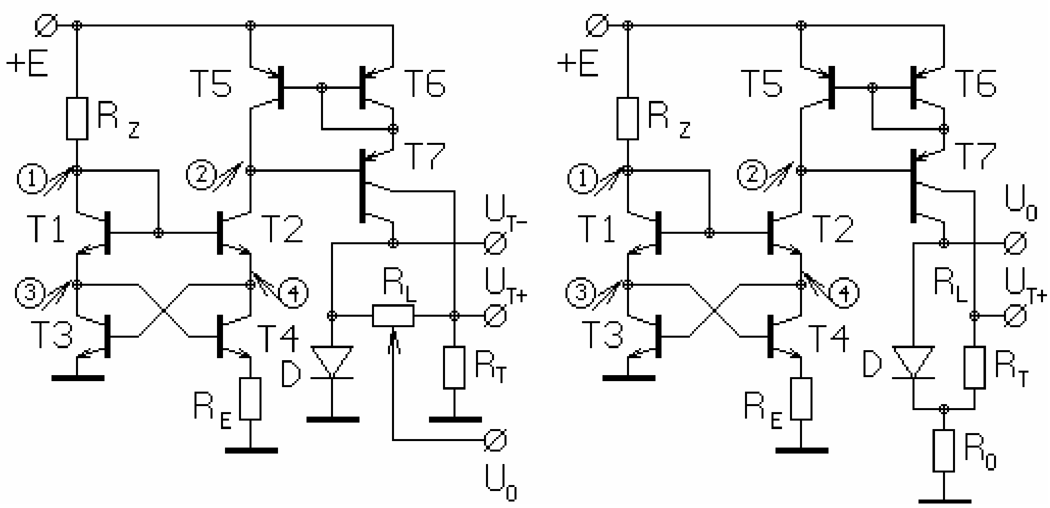


Fig. 1. Electrical scheme of base variant of primary transducer with relative temperature scale

Within one unit temperaturedependent voltage (U_{T+}) and temperatureindependent voltage (U_0) or two temperaturedependent voltages (U_{T+}, U_{T-}) of different sign are formed.

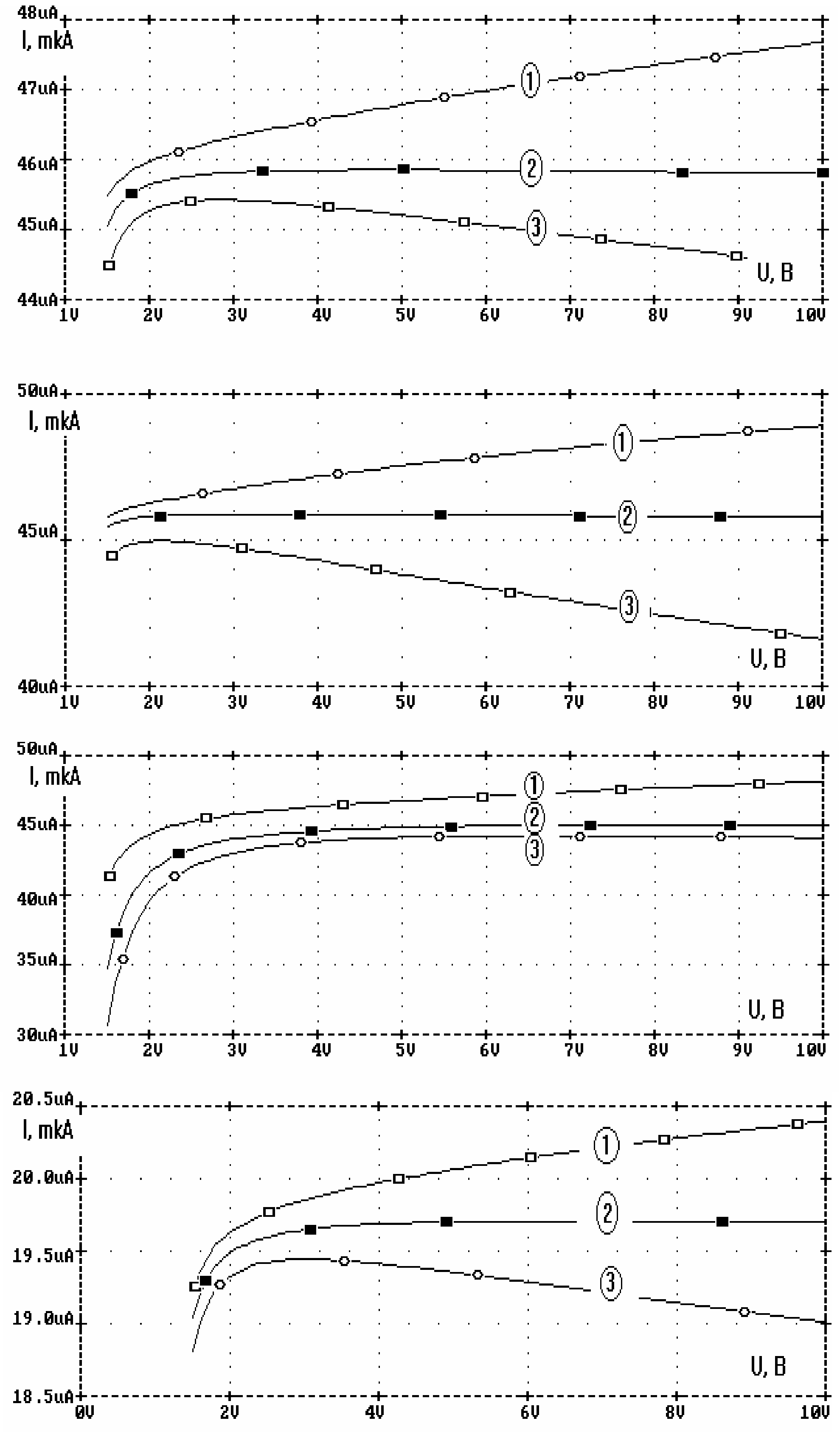
It is shown that current I_T in the first approximation is independent on supply voltage and current through resistor R_Z and is linearly dependent on absolute temperature T: $I_T = \frac{m\varphi_T \ln p}{R_E} = \frac{mk\ln p}{qR_E}T$, where $\varphi_T = {}^{kT}\!/_{q}$ is temperature potential; *m* is factor of nonideality of emitter p-n junctions of transistors; *k* is Boltzmann constant; *q* is electron charge; *T* is absolute temperature; *p* is coefficient of scaling; R_E is resistor in the emitter circuit of stabilizer. Expressions for output voltages U_{T+} and U_{T-}: $U_{T+} = \frac{R_T}{R_E}\frac{mk\ln p}{2q}T$, $U_{T-} = m\varphi_T \ln\frac{I_T}{2I_s}$, where I_s is saturation current. Temperature coefficient of output voltage (TCV) U_{T+} can be given by correlation between resistors R_T/R_E: $\frac{dU_{T+}}{dT} = \frac{R_T}{R_E}\frac{mk\ln p}{2}$ and TCV U_{T-} is determined by a difference between the width of the semiconductor forbidden gap and voltage drop on p-n-transition: $\frac{dU_{T-}}{dT} = -\frac{mE_{G0} - U_T}{T} - \frac{2mk}{q}$, where E_{G0} is the width of silicon forbidden gap, value of which is given for the temperature of absolute zero E_{G0} =1,205V. After subtracting of voltages U_{T+} and U_{T-} in some proportion, we receive the output signal in relative temperature scale.

In the result of investigations the optimal correlation between the resistors of circuit R_Z and R_E, at which the initial current of primary transducer unit is independent on supply voltage is defined:

$$\frac{R_Z}{R_E} = \frac{U_Z}{\left[\sqrt{\left(\frac{1+\ln p}{2}\right)^2 + \frac{U_Z}{|U_a|}} - \frac{1+\ln p}{2}\right]\beta m\varphi_T \ln p}.$$

where U_Z is voltage drop on a resistor R_Z, U_A is early voltage.

At $\frac{U_Z}{|U_a|}\left(\frac{2}{1+\ln p}\right)^2 << 1$ in the first approaching $\frac{R_Z}{R_E} = \frac{|U_a|(1+\ln p)}{\beta m\varphi_T \ln p}$. The current-voltage characteristic of functional stabilizer for received optimal correlations between the resistors of circuit is optimized [2].



RE=1K; p=5;
β=100; |Va| =70V
at RZ=10K-①,
RZ=17K-②,
RZ=30K-③;

RE=1K; p=5;
β=100; |Va| =35V
at RZ=5,0K-①,
RZ=8,5K-②,
RZ=30K-③;

RE=1K; p=5; β=30;
|Va| =70V
at RZ=30K-①,
RZ=70K-②,
RZ=100K-③;

RE=1K; p=2;
β=100; |Va| =70V
at RZ=30K-①,
RZ=38K-②,
RZ=50K-③.

Fig. 2. Dependence of output current I_{out} on supply voltage of functional stabilizer of thermosensitive IC at the optimized value of correlation R_Z/R_E (R_E=1 kOhm) at p=5; β=100; /Va/=70V at RZ=40 kOhm-①, RZ=45,5 kOhm-②, RZ=50 kOhm-③, RZ=55 kOhm-④

On the basis of revealed appropriateness the new thermosensitive IC with relative temperature scale, functional possibilities of which are extended, were created. They are thermosensitive IC with exponential, quazilinear and linear characteristics of transduction.

For developed thermosensitive IC with exponential characteristic of transduction the typical value of measuring range is in the limits of $T_0 \pm 20$ ^{0}C, and at the change of reference temperature T_0 corresponding correction of reference voltage on p-n junction is foreseen. Developed IC are characterized by high steepness of dependence of 10 to 20 %/K, minimum energy consumption (from 2 V). Example of electrical circuit of thermosensitive IC with exponential characteristic of transduction into output current is shown in fig.3. A circuit consist of the functional stabilizer of current I_T on T_1 - T_4, R_1, R_2, operational amplifier on T_6 - T_{14}, R_3, converting p-n junction on T_{13} in diode connection and resistor R_0, the value of which sets a reference temperature.

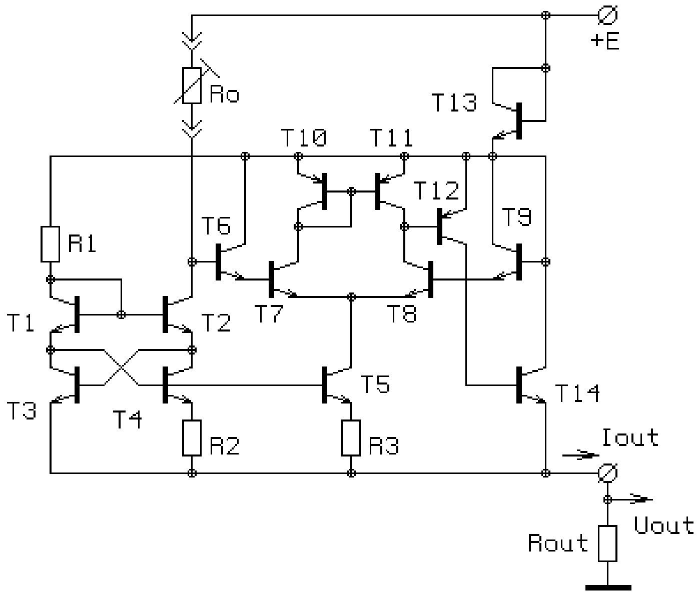


Fig. 3. Circuit of bipolar thermosensitive IC with exponential characteristic of transduction into output current

Normal functioning of circuit is provided already at supply voltage of 2 V. Minimal current of consumption, the value of which determines the low limit of output signal, is equal (30...100) μA and is set by resistors R_2, R_3 and coefficient of scaling of active area of functional stabilizer transistors .

The results of investigations of load resistor voltage which is formed by considered thermosensitive IC are given in table.

Results of investigations of transduction function of thermosensitive IC with exponential characteristic

t, ^{0}C	26	28	30	32	34	36	38	40	42	44	46
U, V	0,377	0,484	0,616	0,774	0,958	1,167	1,396	1,635	1,875	2,102	2,306

Reference temperature is chosen in the limits of measuring range of medical thermometers. It follows from data, that steepness of transduction at $T_0 = 36$ ^{0}C is equal 10 % per 1 degree, however at the increase of temperature it decreases. Obviously, that transduction function of such IC is useless for forming of high-accuracy devices, however such IC can be used in the systems of relay type, for example, with the direct control of the elements of digital technique, in the systems of thermostat control, systems of protection from overheat, in the fire-prevention signaling and other systems [3]. Improvement of metrological characteristics foresees the usage of other principles of transduction.

Thermosensitive IC with quazilinear characteristics are built on differential cascade [4]. They are characterized also by the high steepness of transduction - from 5 to 8%/C in the narrow temperature range.

Given temperature transducers can be used in microelectronic temperature scaners, temperature-gradient transducers, temperature sensors of endo- and exothermic reactions, etc. The example of scheme realization of thermosensitive IC with quazilinear temperature dependence of current in the IC supply circuit is shown in fig. 4. Elements R_1, T_1 - T_7 R_2, R_T, D_1, D_2 are primary transducer; T_{10},T_{11} are differential cascade with displacement on the current source of T_{12}, R_3, elements T_{13}-$T_{21,}$ R_4 are operational amplifier; resistors R_{01}, R_{02} provide corresponding scaling of output current. Results of investigations of output signal of thermosensitive IC with quazilinear temperature dependence of current in the supply circuit on the load resistor R_{out} = 5 kOhm are given in fig. 5. Supply current of IC up to temperature value of t = 34 ^{0}C is of insignificant temperature dependence (in the scale of the given graph initial dependence I_{out} on an absolute temperature is not observed), and in the range of (34- 44) ^{0}C the quazilinear transduction function with more than double growth of output current takes place. Thus, characterized by the high steepness of transduction and enouth linearity, the considered group of thermosensitive IC allows with high resolution to measure the temperature within the limits of a few degrees in relation to its reference value. Resolution of measuring is determined only by temperature influence of IC on the investigated object.

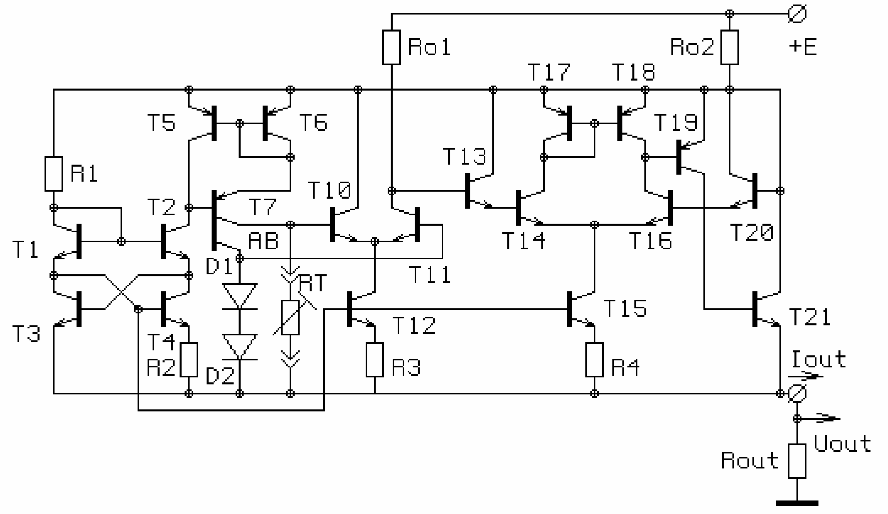


Fig. 4. Circuit of bipolar thermosensitive IC with quazilinear characteristic of transduction into output current

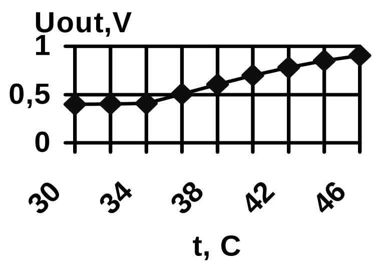


Fig. 5. Results of investigations of initial signal thermosensitive IC with quazilinear temperature dependence of current in the circuit of supply on the load resistor R = 5 kOm

The third type of thermosensitive IC are IC with the linear relative temperature scale which allow to minimize consumption energy (units of milliwatts) and number of leads – from three leads. The unreproducement of characteristics of analysed thermosensitive IC is 2...5 %, and nonlinearity of transduction function in the temperature range of (- 50...+100)^{0}C is 1...2 %.

Thus, after investigations new approaches to creation of thermosensitive IC with relative temperature scale on the basis of revealed dependencies were considered. Developed single chip IC allow to minimize sizes; output signal of these IC is stable in relation to supply voltage (instability of output signal is equal 0.01...0.05%). These IC are characterized by minimum supply voltage (from 2V), simplicity of structure, what allows to make the low cost of their production; by possibility of temperature measuring in a narrow temperature range (from 1^0C and more). Functions of these IC are extended.

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ЛАЗЕРНО-СТИМУЛЬОВАНЕ ОСАДЖЕННЯ ТОНКИХ ПЛІВОК ДЛЯ ВИГОТОВЛЕННЯ ІНТЕГРАЛЬНИХ МІКРОСХЕМ

Проаналізовано методи лазерно-стимульованого осадження тонких плівок та наведено оптимальні режими лазерного осадження міді та нікелю.

In a paper the methods of laser-induced precipitation of thick film were carried out. The optimal regimes of laser precipitation of copper and nickel were presented.

Нині майже всі операції напівпровідникової електроніки при виготовленні інтегральних мікросхем (ІМС) можуть бути виконані за допомогою лазерів . Лазерна технологія забезпечує високу роздільну здатність, локальність, високу швидкість обробки поверхні та можливість використання малоопераційних технологій.

Цікавим є використання рідкофазного лазерного осадження матеріалів для осадження тонких плівок. В основі майже всіх процесів підгонки електричних параметрів плівкових елементів, а також процесів розмірної обробки, коригування топології лежить метод видалення частини плівкового покриття лазерним, електрохімічним або механічним способом. Але всі ці методи не дають змоги відновлювати пошкодження з'єднань або зменшувати номінали резисторів. Застосування локального лазерного осадження дає змогу зменшувати номінали резисторів, збільшуючи геометричні розміри, виправляти дефекти металізації типу "розрив", "прокол", коригувати дефекти фотошаблонів.

Метою нашої роботи було осадження плівок Cu, Ni, Cr на плівкові шари Cr, Ni, NiCr, Cu.

Лазерно-стимульоване рідкофазне осадження можна здійснювати двома методами – електрохімічним і безелектродним. Принцип електрохімічного осадження полягає в тому, що звичайне електрохімічне осадження в електролітичній ванні локалізується в області електрода в місці опромінення лазерним променем. Швидкість осадження підвищується на 3 – 4 порядки [1] . Скануючи променем поверхню електрода, можна одержувати потрібний рисунок без застосування маски. Різке підвищення швидкості осадження в області опромінення катода пояснюється термічною дією лазерного променя на межу розділу "електроліт–катод", внаслідок якого виникає локальне збільшення струму в цій області порівняно з темновими областями катода [2] .