Template Synthesis of Nanomaterials based on Titanium and Cadmium Oxides by the Sol-Gel Method, Study of their Possibility of Application As A Carbon Monoxide Sensor (II)

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Abstract

The influence of the dopant on the regularity of the sol-gel synthesis of a gas-sensitive material based on tetraethoxysilane and metal oxides (Ti and Cd) in the presence of a template was studied. Analysis of the composition of the synthesized nanocomposites by DTA, XRD, and SEM showed that the elemental composition of HCM corresponds to the composition of the components used in their preparation. To obtain highly porous films, heat treatment of HCM at 400-450 ^{0}C is recommended. Samples of thin films of the TEOS/75TiO_2+CdO composition, which are gas sensitive to CO, have been obtained. Selective sensors for carbon monoxide (II) based on the developed HCMs have been created and optimal conditions have been established that ensure the highest sensitivity and selectivity of the developed sensors.

Keywords: Nanomaterial, Titanium Oxide, Cadmium Oxide, Template Synthesis, Gas Sensitive Material, Semiconductor Sensor, Carbon Monoxide.

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INTRODUCTION

Special attention in the world deserve scientific research on the development and improvement of methods for analyzing the composition of atmospheric air and process gases [1,2]. Carbon monoxide is one of the toxic and explosive components of atmospheric air [3–5]. In this regard, the development of semiconductor gas-sensitive materials and the creation on their basis of selective semiconductor sensors that provide the determination of carbon monoxide (II) in atmospheric air, process and exhaust gases is an important task [6–8]. The characteristics of semiconductor sensors depend on various factors, including the composition of gas sensitive materials, which play an important role in ensuring high sensitivity and selectivity in determining the composition of a gas mixture [9, 10].

The aim of the work is the development of selective semiconductor sensors for the determination of CO.

EXPERIMENTAL TECHNIQUE

TiO_2 and CdO were used as a dopant in the template synthesis of gas-sensitive materials (GSM) for semiconductor sensors (SPS) of carbon monoxide (II). The uniqueness of titanium and cadmium oxides as a dopant in the synthesis of HCM for a semiconductor carbon monoxide sensor is caused by a combination of their physical and chemical properties [11, 12]. The electrical conductivity of TiO_2 and CdO changes reversibly as a result of surface reactions occurring at 100-500 0C with the participation of chemisorbed oxygen and gas mixture components [13]. The advantages of titanium and cadmium oxides over other oxides are also their low cost, chemical resistance and ease of fabrication of films based on them. Citric acid served as a structure-controlling agent during the synthesis of the HFM sensor. When conducting research, tetraethoxysilane (TEOS) $(C_2H_5O)_4Si$ os. was used as starting compounds for the synthesis of gas-sensitive materials. TU 2637-059-44493179-0, the solvent for TEOS was doubly distilled ethanol, and hydrofluoric acid was used as a catalyst for the sol-gel process. Experiments on the synthesis of HCM were carried out at the ratio of the initial components: TEOS:C_2H_5OH:H_2O:HF=1:25:15:0,1. $TiCl_4$ and $CdC1_2$ were used as sources of TiO_2 and CdO in the experiments.

Results and Discussions

Template synthesis of porous silica materials in the presence of a dapant was carried out according to the procedure described in [14, 15]. To study the effect of the dopant on the stability of the film-forming solution, TEOS solutions were prepared in purified ethanol at a molar ratio of TEOS: alcohol=1:25. The resulting mixture was stirred for 2 hours, then left for 2 hours at room temperature. After that, a mixture of the corresponding salts dissolved in distilled water in the presence of an acid (catalyst) was added to the resulting solution with constant stirring. The resulting mixture of TEOS: ethanol: water: HF (1:25:15:0.1) was homogenized for 2 hours at a temperature of 25 0C using an automatic disperser UDNP-2T for 60 minutes. As a result of the experiments carried out, it was established that the stability of the solution depends on the composition and amount of salts added to the solution. Figure 1 shows the dependence of the stability of the film-forming solution on the composition of the initial mixture. In the experiments, the molar ratio TEOS/dopant = 2/1.

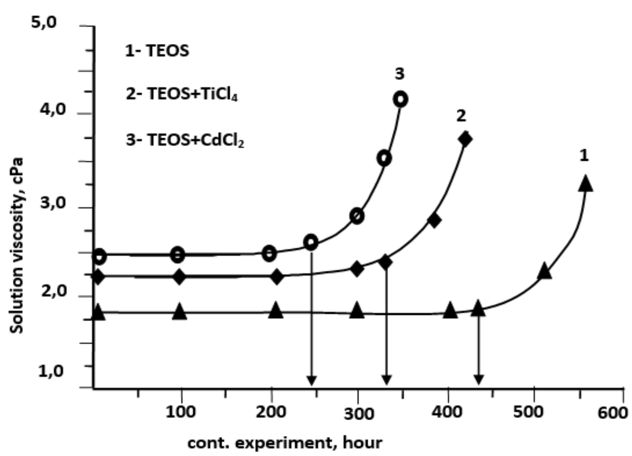

Fig. 1. Dependence of the stability of the film-forming solution on the composition of the dopant

As can be seen from Fig. 1, under analogous conditions, the stability of solutions without a dopant and with a dopant based on $TiCl_4$ and $CdCl_2$, respectively, is equal to 445; 340 and 248 hours. Therefore, under identical conditions, the stability of a solution without a dopant is greater than that of a solution with a dopant. In this case, the stability also depends on the composition of the salts used as a dopant. In the presence of $TiCl_2$, the stability of the sol (340 hours) is greater than that of the solution with $CdCl_2$ (248 hours). The film-forming solution has the ability to form strong and uniform coatings only after a certain exposure time. This time depends on the composition and ratio of components. On the curve (Fig. 1.) of the dependence of the kinematic viscosity of the solution on the time of its aging, two sections can be distinguished, which correlates well with the literature data [16,17]. It is assumed that the area almost parallel to the abscissa axis corresponds to the hydrolysis of silicon alcoholates and the condensation of monomers into dimers. The intensively increasing portion of the curve corresponds to the occurrence of polycondensation processes.

Metal oxides are widely used as gas sensitive materials for chemical sensors [18–20]. During the experiments, the properties of gas-sensitive nanocomposite films synthesized on the basis of titanium oxide and modifying metal oxides were studied. The following metal oxides were chosen as inorganic modifiers: ZrO_2, TiO_2, CdO, ZnO, In_2O_3, NiO, Mo_2O_3, Al_2O_3, SnO_2, which are characterized by high sensitivity to inorganic gases [21-25]. The modifying inorganic additives were introduced into the initial mixture through salts soluble in water and ethanol. In order to determine the possibility of using the obtained films as a gas-sensitive material for a semiconductor carbon monoxide sensor, we studied the change in their electrical conductivity under the action of carbon monoxide. The results obtained are shown in Table 1.

Table 1: Dependence of the signal of the gas-sensitive material on the composition of the metal oxide (n=5, p=0.95, CO content in the mixture 500 mg/m^3, ratio TEOS: metal oxide=1:1).

№	The composition of the HCM	Sensitivity of HCM for carbon monoxide, mV.		
		x±Δx	S	Sr
1	TEOS + ZrO_2	6,7±0,1	0,1	1,49
2	TEOS + TiO_2	28,2±0,4	0,4	1,42
3	TEOS + CdO	23,9±0,2	0,2	0,84
4	TEOS + ZnO	16,3±0,5	0,5	3,07
5	TEOS + In_2O_3	18,0±0,3	0,3	1,67
6	TEOS + NiO	9,8±0,4	0,4	4,08
7	TEOS +Mo_2O_3	4,5±0,1	0,1	2,22
8	TEOS + Al_2O_3	5,3±0,1	0,1	1,89
9	TEOS + SnO_2	13,3±0,3	0,3	2,26

As can be seen from the data in Table 1, of the studied nanocomposite films, the highest sensitivity to CO is characterized by gas-sensitive material based on TEOS, titanium and cadmium oxides.

In this regard, in further experiments the characteristics of films based on TEOS +TiO_2, TEOS +CdO and their mixtures. (TEOS +TiO_2+CdO). On fig. 2. SEM and SDE images of silica materials synthesized on the basis of TEOS and metal oxides: Ti, Cd are shown. Heat treatment of the obtained films was carried out at 400 0C. As can be seen from Fig.2. in the presence of titanium oxide and cadmium, a finely porous silica material is formed.

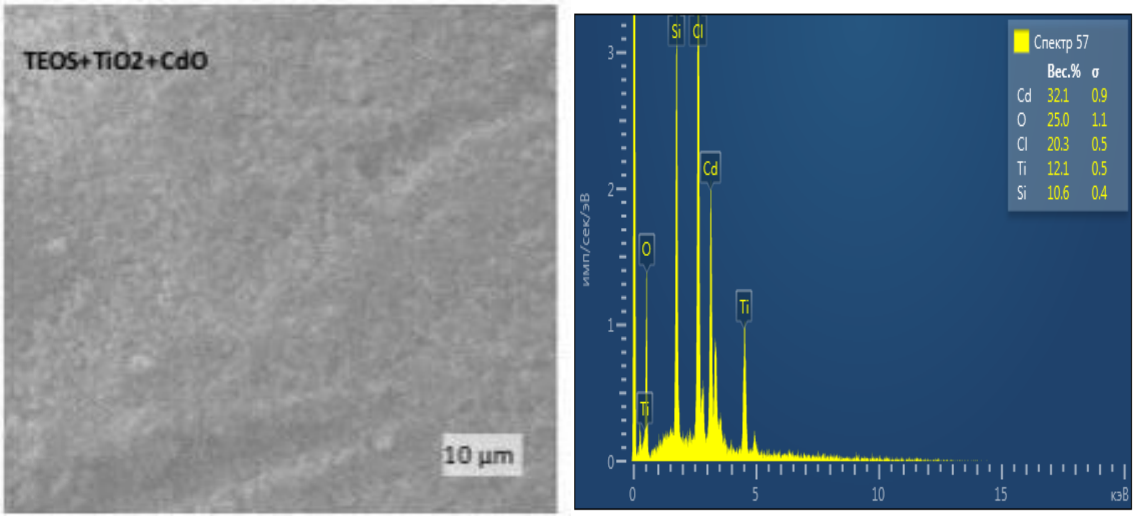

Fig. 2. SEM and SDE image of silica materials synthesized based on TEOS+TiO_2+CdO

From Fig.2. It follows that the elemental composition of the obtained solid nanocomposites fully corresponds to the composition of the initial solution. Thus, the elemental analysis of the obtained nanocomposites (Fig-2.) confirms the correspondence of the obtained films to the initial composition of the sol-gel synthesis of HCM.

As is known, the sensitivity and selectivity of a semiconductor sensor can be controlled by changing the ratio of the components of the initial mixture [26]. Therefore, in the course of experiments, we studied the effect of the ratio of components (titanium and cadmium metal oxides) on the characteristics of the nanocomposite obtained on their basis. The results of studying the dependence of the sensitivity of nanocomposite films on the ratio of their components in the process of determining CO are shown in Table 2.

As a result of studying the sensitivity of a gas-sensitive material based on titanium and cadmium metal oxides, it was found that the highest activity in the process of carbon monoxide monitoring is a mixture of titanium and cadmium oxides obtained at a ratio of 3:1.

Table 2: Dependences of the sensitivity of nanocomposite films on the ratio of their components in the process of CO determination (n=5, p=0.95, SiO_2-metal oxide ratio=2:1)

№	The composition of the HCM	Sensor signal, mV.		
		x±Δx	S	Sr
1	TEOS /(100%CdO)	23,9±0,2	0,16	0,67
2	TEOS /(100%TiO2)	28,2±0,4	0,32	1,14
3	TEOS /(5%TiO_2+95%CdO)	26,7±0,3	0,24	0,9
4	TEOS /(25%TiO_2+75%CdO)	33,2±0,2	0,16	0,48
5	TEOS (50%TiO_2+50%CdO)	38,5±0,1	0,08	0,21
6	TEOS /(75%TiO_2+25%CdO)	42,5±0,4	0,32	0,76
7	TEOS /(95%TiO_2+5%CdO)	37,1±0,3	0,24	0,65

Also, the sol obtained on the basis of this composition is characterized by high stability over time. The stability of the sol obtained on the basis of TEOS/(75%TiO2+25%CdO) (at the ratio of SiO_2/metal oxide=2:1) provides the possibility of preparing gas-sensitive films for more than 80 hours from the moment of its preparation. Therefore, in experiments on the creation of a semiconductor sensor for carbon monoxide as a gas-sensitive sensor material, the possibility of using a composite based on TEOS/(75%TiO_2+25%CdO) was studied.

Thermal analysis of the gas-sensitive material based on TEOS/(75%TiO_2+25%CdO) was carried out on a thermal analyzer in the range from 50 to 850 ^{0}C at a heating rate of 10°C/min. In the experiments, a sample with a mass of 30 mg dried at 100 ^{0}C was used. The resulting thermogram of the sample is shown in Fig.3. According to the results of thermal analysis, it was found that when the samples are heated to a temperature of 850 ºC, two jumps associated with weight loss are observed on the thermogram. Endothermic effects from minima in the temperature range of 120–240 ºC are accompanied by significant weight loss and are associated with the processes of decomposition of crystalline hydrates of salts, evaporation of alcohol, physically adsorbed water and chemically bound water. Endothermic effects in the range of 460–700 ºC are associated with the thermal-oxidative destruction of residual alkoxy groups.

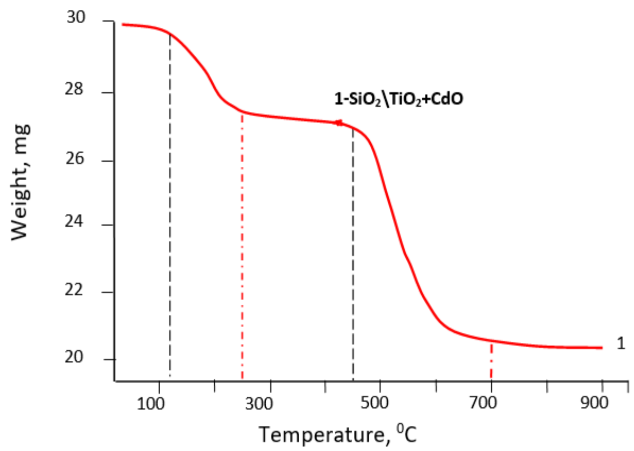

Fig.3. Thermogram of a composite sample $SiO_2\backslash 75TiO_2+25CdO$

Thus, as a result of the studies carried out, the properties of silica based on tetraethoxysilane, hydrolyzed in an acidic medium in the presence of modifying inorganic substances, metal salts (titanium chloride and cadmium chloride), were obtained and studied. The optimal composition and ratio of the components of the gas-sensitive material of the semiconductor carbon monoxide sensor has been established. The use of this gas-sensitive material ensures high sensitivity of the sensor to carbon monoxide. In the course of experiments using optimized parameters and selective gas-sensitive materials, semiconductor carbon monoxide sensors (PPS-CO) were created. The developed sensors provide monitoring of carbon monoxide in a wide range of its concentration. PPS-SO1M and PPS-SO2M are designed respectively to control the micro-concentration and macro-concentration of carbon monoxide in a mixture of gases.

The program for testing the sensor in the operating mode included special experiments related to the selection of the supply voltage, the formation of the device readiness time, dynamic and calibration characteristics, and also the identification of the degree of its selectivity.

The magnitude of the signal and the selectivity of the semiconductor sensor depend on the supply voltage, the change of which leads to temperature variability on the surface of the catalyst of the sensitive elements of the sensor. Increasing the temperature of the sensing elements above the optimum leads to the oxidation of carbon monoxide on the surface of the compensation element catalyst. Reducing the temperature of the catalyst, respectively, reduces the activity of the catalyst of the sensor measuring sensing element. Thus, an increase and decrease in power supply is accompanied by a decrease in the value of the useful signal of the sensor. In the experiments, we used PGM with a CO content of 0.50% vol., the results obtained are presented in Table 3.

Table 3: Dependence of the sensor signal (PPS-CO 2M) on the supply voltage (n=5, p=0.95)

№	Supply voltage, V	Sensor signal, mV		
		$\bar{x} \pm \Delta x$	S	$Sr*10^2$
1	1,00	2,34±0,03	0,020	0,62
2	1,50	12,80±0,02	0,008	0,28
3	2,00	47,90±0,04	0,028	0,08
4	2,50	56,42±0,06	0,022	0,10
5	3,00	51,18±0,06	0,016	0,09
6	3,35	49,51±0,05	0,036	0,07
7	3,50	46,57±0,06	0,040	0,09

It follows from the obtained results that the optimal power supply value for PPS-CO2M is 2.5 V. An increase and decrease in the sensor power supply value are accompanied by a decrease in the PPS value.

One of the main requirements for sensors of fire and explosive components is to ensure the rapidity of component determination (ie, a short transient time), which is established by studying their dynamic characteristics.

Verification of the dynamic characteristics of the developed carbon monoxide sensor includes the study of its temporal characteristics, that is, the time of transients. Before starting the sensor test, it is necessary to set the value of the output (background) signal; for this, purified air and a standard gas mixture were sequentially supplied through five serially connected semiconductor carbon monoxide sensors for 10 min. Checking the dynamic characteristics of the sensor was accompanied by a continuous recording of the transient process of the chart tape of the recorder, the speed of which was chosen such that the graph of the transient process was adequate to GOST 133220-81 "Gas analyzers, industrial automatic". The general technical parameters of the sensor were placed on a segment of a chart tape, 15 cm long.

The change in the concentration at the sensor inlet was noted on the chart tape and was taken as the beginning of the time count. The results of determining the dynamic characteristics of the semiconductor sensor PPS-SO1M and PPS-CO2M are shown in Table 4.

As can be seen from the data, for the developed sensors, the response start time ($t_{0,1}$) is 1-2 s, the constant time ($t_{0,65}$) is no more than 5 s, and the readings settling time ($t_{0,9}$) reaches up to 8 s and the full measurement time (t_p) 9-10 s.

Table 4: Dynamic characteristics of a semiconductor sensor for carbon monoxide (II) (n=5, P=0.95)

№	Concentration of carbon monoxide (II), mg/m^3	Dynamic characteristics of the sensor*, p.			
		$t_{0,1}$	$t_{0,65}$	$t_{0.9}$	$t_п$
1	125	1,0	3	7	10
2	250	2,0	4	7	10
3	500	1,0	4	8	9
4	750	1,0	5	7	10

The results shown in Table 4 show the possibility of using PPS-CO for express determination of carbon monoxide content.

The dependence of the useful analytical signal of PPS-CO on the concentration of carbon monoxide was established in a wide range of its concentration by passing a gas mixture of carbon monoxide in air through the developed sensor.

In experiments, the dependence of the analytical signal of the sensors (PPS-CO1M and PPS-CO2M) on the amount of the determined component was carried out in the range of CO concentrations from 75 to 3000 mg/m^3 and from 0.1 to 3.0 vol.%. Each test point for the measurement range was characterized by six values: three for forward and three for reverse measurement cycles. The analytical signal of the sensors was monitored with a V7-35 voltmeter after a constant value was established (at least 1 min after the standard mixture was supplied to the instrument). The results of the experiments to determine the calibration characteristics of semiconductor sensors for carbon monoxide are shown in Table 5.

Table 5: Dependence of the analytical signal of the sensors on the amount of the determined component (C_{CO}) in the PGM (n=5, P=0.95)

PPS-SO1M				PPS-SO2M			
CO content, mg/m^3	Sensor signal, mV			CO content, vol.%	Sensor signal, mV		
	$\bar{x}\pm\Delta x$	S	Sr*10^2		$\bar{x}\pm\Delta x$	S	Sr*10^2
75	4,86±0,1	0,017	1,65	0,10	20,3±0,2	0,012	1,17
225	14,4±0,2	0,011	1,11	0,60	102,5±0,3	0,004	0,35
900	53,8±0,3	0,004	0,45	1,40	243,0±0,7	0,003	0,34
1750	101,0±0,8	0,006	0,64	2,00	366,0±1,3	0,004	0,42
3000	174,5±1,3	0,006	0,60	3,00	496,5±1,2	0,003	0,29

As follows from the given data, in the studied interval, the dependence of the signal of the semiconductor sensors PPS-CO 1M and PPS-CO2M on the concentration of carbon monoxide in the OPO is linear.

The service life of a gas analyzer is closely related to the stability of its signal. As is known, semiconductor sensors are characterized by high signal stability [27, 28]. Checking the constancy of the values of the input signals over time was controlled during continuous operation for 2000 hours. The measurement of the input signal during the regulated time interval was recorded on the chart tape of the recorder. When processing the test results, random single outbursts of the output signal were not taken into account with the duration of each outburst of no more than 10 s. Experiments to study the stability of the carbon monoxide sensor were carried out under normal conditions of 740 ± 20 mm Hg. Art. In the experiments, ASG with a carbon monoxide content of 650 mg/m3 and 1.50 vol. % was used.

Table 6: The results of determining the stability of PPS-CO (n=5, P=0.95)

№	Time, hour	PPS-SO 1M SSO=650mg/m ^{3}			PPS-SO 2M SSO=1.50% vol.		
		$\bar{x}\pm\Delta x$	S	Sr·10^2	$\bar{x}\pm\Delta x$	S	Sr·10^2
1	1	42,5±0,4	0,32	0,76	254,9±1,6	1,29	0,5
2	24	42,0±0,3	0,24	0,57	253,6±1,1	0,88	0,35
3	96	42,1±0,3	0,24	0,57	254,5±1,3	1,05	0,41
4	220	41,5±0,2	0,16	0,39	255,1±2,1	1,69	0,66
5	350	41,9±0,6	0,48	1,15	256,0±1,6	1,29	0,5
6	450	42, 0±0,3	0,24	0,59	254,2±1,8	1,45	0,57
7	550	41,5±0,7	0,56	1,36	254,8±19,	1,53	0,61
8	650	42,1±0,8	0,64	1,53	255,2±2,0	1,61	0,63
9	750	42,3±0,3	0,24	0,57	255,8±1,6	1,29	0,52
10	850	41,8±0,4	0,32	0,77	254,1±1,1	0,88	0,35
11	1000	42,3±0,9	0,42	1,31	253,9±1,3	1,05	0,41
12	1200	41,4±0,5	0,41	0,97	256,1±1,9	1,53	0,60
13	1400	42,0±0,4	0,32	0,77	255,7±1,8	1,45	0,57
14	1600	41,6±0,5	0,42	0,97	253,8±2,3	1,85	0,73
15	1800	42,6±0,5	0,40	0,94	254,7±1,7	1,37	0,54
16	2000	41,9±0,7	0,56	1,34	254,9±2,1	1,29	0,66

Table 7: Results obtained from the determination of the maximum deviation of the carbon monoxide sensor

Sensor	U_{max}, мВ	U_{min}, мВ	Δt_g	Tolerance. according to GOST
CCO=650 mg/m ^{3}	42,6	41,4	1,2	5,0
CCO=1.50 vol.%	256,0	253,6	2,4	5,0

Our calculations show that the value of Δtg for a regulated time interval is 1.2 and 2.4% (Table 7.).

The change in the value of the output signal over a regulated time interval was estimated by the maximum divergence of the sensor signal:

$$\Delta tg = (Up_{max} - Up_{min})\, 100/U_{шк} \quad (1),$$

where Δtg is the limit of the permissible change in the output signal for a regulated time interval; Up_{max}, и Up_{min}- maximum and minimum signal discrepancies; $U_{шк}$- instrument scale (KSP 0-50 mV).

Our calculations show that the value of Δtg for a regulated time interval is 2.8 and 0.94%

In objects where carbon monoxide content control is required, in addition to carbon monoxide, a number of combustible and non-combustible substances are also contained [29,30]. The selectivity of the carbon monoxide sensor was determined in the presence of combustible components (hydrogen, gasoline and methane vapors) present locally in controlled objects. The experiments were carried out at a temperature of 20 ^{0}C and a pressure of 730±10 mm Hg, a gas mixture was supplied to the sensor input for 5 minutes, followed by recording the instrument readings.

The device was tested by 5 parallel determinations for each gas mixture. The results obtained when establishing the selectivity of the developed carbon monoxide sensors are presented in Table 8.

As follows from the above data, the developed sensor makes it possible to selectively determine carbon monoxide in atmospheric air and process gases in the presence of methane, hydrogen, and gasoline vapors.

Table 8: The results of the establishment of selectivity in the determination of carbon monoxide (n = 5, P = 0.95)

№	Introduced gas mixture, vol.% (mg/m ^{3})	Found carbon monoxide, vol.% (mg/m^3)	
		$\bar{x}$ ±Δx	Sr·10^2
PPS-CO1 M C_{CO}, mg/m ^{3}			
1	CO 650+ air	642±7,4	0,93
2	CO 650+$CH_4$1000+ air	653±9,6	1,18
3	CO 150+H_2 1000+ air	645±7,8	0,97
4	CO 650+CO_2 1000+ air	652±8,7	1,07
5	CO 650+бенз. 0,50+ air	635±7,0	0,89
PPS-CO2 M C_{CO}, about.%			
6	CO 0.5 + CO 0.90 + air.	0,52±0,02	3,09
7	CO 0,5+CH_4 0,90+ air	0,51±0,01	1,58
8	CO 0,5+H_2 0,90+ air	0,51±0,02	3,15
9	CO 0,5+CO_2 0,90+ air	0,52±0,01	1,55

Checking the influence of the temperature of the analyzed gas mixture on the value of the PPS-CO input signals was carried out in the range of -10 ± 50 ^{0}C. In the experiments, HS was used with a carbon monoxide content in a mixture of 420, 970, 2300 mg/m^3 and 0.33, 0.75, 1.60 vol. %. The sequence of temperature setting in the analyzed mixture: +20 0C (optimum temperature set when determining the sensor signal): 0, 10, 25, 30, 40 and 50 ^{0}C. At each temperature, it was kept for 1 hour, after which the HS was applied and the sensor signal was taken. The results of determining the change in the signal of PPS-CO1M and PPS-CO2M, due to changes in ambient temperature, are presented in Table 9.

Table 9: Dependence of the PPS-CO signal on the temperature of the gas mixture (n= 5, P = 0,95).

Temperature, ^{0}C	Sensor signal, mV					
	PPS-SO1MS$_{CO}$-650 (mg/m ^{3})			PPS-CO2 MS$_{CO}$-0.5 about.%		
	$\bar{x}$ ±Δx	S	Sr·10^2	$\bar{x}$ ±Δx	S	Sr·10^2
+20	42,8±0,3	0,24	0,56	84,5±0,2	0,16	0,19
0	41,3±0,4	0,32	0,78	85,1±0,7	0,56	0,66
-10	42,0±0,2	0,16	0,38	84,5±0,8	0,64	0,76
+25	41,3±0,3	0,24	0,58	83,1±04	0,32	3,87
+30	41,5±0,5	0,4	0,97	84,6±0,4	0,32	0,38
+40	41,4±0,4	0,32	0,78	85,0±0,6	0,48	0,57
+50	42,1±0,6	0,48	1,15	84,8±0,5	0,40	0,47

From the data given in Table 9, it follows that in the studied range, changes in the temperature of the gaseous medium do not have a significant effect on the values of the analytical signal of the sensor.

Pressure tests were carried out in the range of 600-900 mm Hg. To determine the effect of pressure on the operation of the sensor, the pressure in the sensor chamber was set from 600 to 900 mm Hg (with a difference of 50.0±1.5 mm Hg) and after one hour the readings of the device were recorded when passing a standard mixture containing oxide carbon 600mg/m^3 and 1.00 vol.%. The results of the experiments to determine the effect of pressure on the useful analytical signal are presented in Table 10.

Table 10: The results of determining the concentration of carbon monoxide at various pressures (n = 5,P = 0,95)

Gas mixture pressure, mm Hg	Sensor signal, mV			
	PPS-CO1M, C_{CO}-1000 mg/m ^{3}		PPS-CO2 M, C_{CO}-1,50 about.%	
	$\bar{x}$ ±Δx	Sr•10^2	$\bar{x}$ ±Δx	Sr•10^2
600	65,4±0,4	0,9	256,1±1,8	0,9
650	64,9±0,3	0,8	251,7±1,8	0,6
700	65,0±0,2	0,6	254,7±1,3	0,8
750	65,1±0,5	0,8	255,6±1,6	0,5
800	64,6±0,3	1,2	254,7±2,1	0,9
850	64,9±0,6	0,6	252,8±2,0	0,5
900	65,3±0,4	0,8	254,9±1,9	0,6

As follows from the given data, in the studied range, a change in the pressure of the gaseous medium has practically no effect on the value of the sensor output signal. Pressure tests were carried out in the range of 600-900 mm Hg. carbon monoxide 600, mg/m^3 and 1.00, vol.%. The value of the relative standard deviation (Sr*10^2) due to non-measured components does not exceed 2.46. A change in the flow rate of the gas mixture in the studied interval (2 - 40 l/h) does not significantly affect the value of the sensor output signal. Thus, as a result of the experiments carried out, a selective semiconductor carbon monoxide sensor was developed, which provides an express determination of carbon monoxide in a wide range of its concentration in atmospheric air and process gases. The developed semiconductor carbon monoxide sensors in terms of accuracy and reproducibility are in no way inferior to well-known foreign analogues, while retaining the following characteristics: rapidity, portability, ease of manufacture and operation. The value of the relative standard deviation (Sr) due to unmeasured components does not exceed 0.05. A change in the flow rate of the gas mixture in the studied interval (5 - 50 l/h) does not significantly affect the value of the sensor output signal. The output signal of the sensors also does not depend on the location in space and the angles of inclination, which makes it possible to classify the developed sensors (according to GOST-13320-82) as independent ones.

CONCLUSION

Thus, the effect of a dopant on the regularity of the sol-gel synthesis of a gas-sensitive material based on tetraethoxysilane and metal oxides (Ti and Cd) in the presence of a template was studied. Analysis of the composition of the synthesized nanocomposites by DTA, XRD, and SEM showed that the elemental composition of HCM corresponds to the composition of the components used in their preparation. To obtain highly porous films, heat treatment of HCM at 400-450 ^{0}C is recommended. Samples of thin films of the TEOS/75TiO2+CdO composition, which are gas sensitive to CO, have been obtained. Selective sensors for carbon monoxide (II) based on the developed HCMs have been created and optimal conditions have been established that ensure the highest sensitivity and selectivity of the developed sensors.

REFERENCES

Cattrall Robert W. Chemical sensors. -M.: Scientific world, 2000.-144 p.

Gaman V.I. Physics of semiconductor gas sensors. - Tomsk: Publishing house of scientific and technical literature, 2012. – 110p.

Sultanov M.M., Abdurakhmanov E. Thermocatalytic gas analyzer for the determination of carbon monoxide. // Universum: technical sciences, electron. scientific magazine. 2018. №2 (47).

Markov V.A., Bashirov R.M., Gabitov I.I. Toxicity of exhaust gases of diesel engines. M.: Publishing house of MSTU im. N. E. Bauman, 2002. - 376 p.

Eshkobilova M.E., Sidikova H.G., Abdurakhmanov E.Metrological characteristics of the semiconductor gas analyzer of carbon monoxide "PGA-CO"// Vestnik NUUz2021.3/2/1.– C. 299-306.

Gas analyzers, gas detectors, analytical instruments. (Carbon monoxide analyzers (CO) //.info@ gazanalizator.ru 12.02.2021

Abdurakhmanov E. Sensor for selective monitoring of carbon monoxide in the air and industrial gaseous emissions // Zh. anal. and cont. – M., 2004. - № 2(8). - p. 165 - 168.

Abdurakhmanov E., Sultanov M., Daminov G., Sidikova Kh., Eshkobilova M., Abdurakhmonov B., Kholboev O. Chemical sensor for monitoring carbon monoxide from transport emissions // SCINCE AND EDUCATION ISSN 2181-0842 VOLUME 1, ISSUE 1, APREL 2020,–. 37-43 p.

Melgunova E.A. Synthesis of mesoporous materials using Pluronic P 123 surfactant and study of their texture: Cand. cand. chem. Sciences: - Novosibirsk, 2010.–p. 144.

Abdurakhmanov I. E., Kuchkarov O. A., Abdurakhmanov E. Selectivity and stability of signal of ammonia semiconductor sensors with membrane coatings based on SiO2/TiO2+Fe2O3 structure // European Sciences Review Scientific journal.Vienna-2019. № 11–12. -p.7-12.

Molodechkina T.V. Alloyed titanium oxides as a basis for the formation of sensitive elements of gas sensors // Vestn. Polots. state university Series B. Applied Sciences. -2011,№ 3. -. 81–87 p.

Egorov, A.A. Chemical sensors: classification, principles of operation, areas of application / A.A. Egorov, M.A. Egorov, Yu.I. Tsareva // Physical and chemical kinetics in gas dynamics: electronic journal. – 2008. – T. 6 0. URL: http://chemphys.edu.ru/issues/2008-6/articles/273.

Abdurakhmanov I. E., Kuchkarov O. A., Abdurakhmanov E. Gas sensitivity speed of ammonia semiconductor sensors based on metal – oxide films SiO2/TiO2+ Fe2O3 //Rasayan Journal of chemistry. Vol.13. №. 3. 2020. pp. 1486-1490.doi.org/10.31788/RJC.2020. 1335718. (Scopus).

Gorbunova O.V. Formation of micro- and meso porous silica materials under conditions of sol-gel synthesis in the presence of polyethylene glycol // Abstract of the dissertation for the degree of Candidate of Chemical Sciences. –Omsk, 2020/14.- 21 p.

Abdurakhmanov I.E., Begmatov R.Kh., Abdurakhmanov E. Sol-gel method for the formation of gas-sensitive metal oxide films on an inert substrate//Eurasian Union of Scientists (ESU) Monthly Scientific Journal.-Moscow, 2019.-№ 9 (66).- 29-32 p.

Abdurakhmanov I. E. Creation of chemical sensors based on metal oxide composites for the determination of toxic and explosive gases Abstract of the dissertation of Doctor of Chemical Sciences (DSc). Tashkent 2021. 63 p.

Pronin I.A. Physical and chemical features of the formation of hierarchical nanostructures for sensor elements: Abstract of the dissertation for the degree of candidate of technical sciences / St. Petersburg State Electrotechnical University "LETI" them. IN AND. Ulyanov (Lenin).-St. Petersburg. 2015. 24 p.

Abdurakhmanov I. E., Begmatov R. Kh., Abdurakhmanov E., Kholboev O. N., Kholmirzaev F. F. Metrological parameters of semiconductor sensors of hydrogen sulfide SCS-H2S with membrane coatings based on tungsten and copper oxides// IOP Conference Series: Materials Science and Engineering. To cite this article: I E Abdurakhmanov et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 862 062084 862(2020) 062084.pp.1-6. Doi: 10.1088/1757-899X/862/6/062084.

Kuchkarov O.A., Abdurakhmonov I.E., Begimkulov Zh.N., Mamirzaev M.A., Khamraeva D.A., Abdurakhmanov E. Investigation of particular parameters of a semiconductor ammonia gas analyzer//IOP Conference Series: Materials Science and Engineering. To cite this article: O A Kuchkarov et al 2020 IOP Conf. Ser.: Mater.Sci. Eng. 862062101. pp.1-6. doi:10.1088/1757-899X/862/6/062101

Sidikova Kh. G., Abdurakhmanov I. E., Mumunova N. I., Kholboev O. N., Abdurakhmanov E. Development and research of metrological characteristics of selective thermocatalytic methane (natural gas) sensor// IOP Conference Series: Materials Science and Engineering. To cite this article: Kh G Sidikova et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 862 062102.P.1-6. doi: 10.1088/1757-899X/862/6/ 062102.

Abdurakhmanov I.E., Begmatov R.Kh., Abdurakhmanov E. Sol-gel method for the formation of metal oxide gas-sensitive films on an inert substrate // Eurasian Union of Scientists (ESU). Monthly scientific journal. Russia-2019. No. 9 (66). part 4. - 29-32 p.

Begmatov R.Kh., Abdurakhmanov I.E., Abdurakhmanov E. Hydrogen sulfide gas sensors based on semiconductor films SiO2/WO3-CuO// Universum: Chemistry and biology. Electronic scientific journal. Russia -2019. № 12(66), № 2

Moshnikov V.A., Myakin S.V., Gracheva I.E., Nalimova S.S., A method for obtaining a gas-sensitive material based on zinc oxide to acetone vapor // RUS patent 2509302 15.10.2015. -22 p.

Zolotukhin I.V., Kalinin Yu.E., Stogney O.V. Electrophysical properties of the nanocomposite SnOx: MnOy // New directions of physical materials science. -Voronezh: VSU Publishing House, 2000.-360 p.

Grinchuk A.P., Taratyn I.A., Khatko V.V. Development of gas sensors for monitoring combustible gases // Instruments and measurement methods. – 2010, № 1. –51–55 p.

Abdurakhmanov Ilxom Eergashboyevich1, Begmatov Rizamat Khushvaqtovich, Abdurakhmanov Ergashboy, Kholboev Orif Nurmatovich Semiconductor Sensor for Hydrogen Sulfide on the Basis of Tungsten and Copper Oxides// International Journal of Management and Fuzzy Systems.2020. 6(4) pp. 72-79. doi: 10.11648/j.ijmfs.20200604.13

Kuchkarov O.A., Abdurakhmanov I.E., Abdurakhmanov E. Stability of a semiconductor ammonia sensor // Proceedings of the International Scientific and Practical Conference "Modern Science: Actual Problems and Ways of Their Solution". Dushanbe, Tajikistan-2019. Scientific Publishing Center "World of Science". Russia -2019. -.8-12 p.

Kh. G. Sidikova, Eshkobilova M.E., E.Abdurakhmanov, Термокаталитический сенсор для селективного мониторинга природного газа //VI- Международные научные практической конференции

GLOBAL SCIEN CEAND INNOVATIONS 2019 CENTRAL ASIYA: Нур-Султан, 2019, 9-13 май,– С. 235-238

Muminova, N. (2020). http://sci-conf. com. ua Abstracts of V International Scientific and Practical Conference. JSPI Scientific Publications Archive.

Muminova, N. (2020). http://sci-conf. com. ua. Oxidation of hydrocarbons on the catalyst surface of the thermocatalytic sensor. JSPI Scientific Publication Archive.

E. Abdurakhmanov, Kh. G. Sidikova, I. E.Abdurakhmanov, N. I.Muminova, Copyrightⓒ Elaboration And Investigation Of Metrological Characteristics Of Semi-Conductor Sensor Of Methane. Архив Научных Публикаций JSPI. Vol. 29, No. 7, (2020), pp

Kholmirzayev F.F., Eshkobilova M.E., Urokov D.M., Abdurakhmanov E. The influence of temperature on the sensitivity of a semiconductor methane sensor.//Materials of the Republican conference "Development of analytical chemistry in Uzbekistan". Tashkent. 2018. 78-81 p.