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YARIMO‘TKAZGICH SENSORLAR BO‘YICHA QURILMALARNI XARAKTERISTIKALARINING ENERGIYA SARFINI KAMAYTIRISH, TERMAL AYLANISH REJIMINI VA YANGI MODIFIKATORLARNING O‘ZARO TA’SIRINI O‘RGANISH

ANNOTATSIYA

Yarimo‘tkazgich-dielektrik tuzilmalarini amaliy qo‘llash sohasida dielektrik chegara sohasida zaryadlarning to‘planishi kuzatiladi. Bu esa yarimo‘tkazgich-dielektrik asosida yaratilgan elektron qurilmalarning ishchi xarakteristikasiga jiddiy ta’sir o‘tkazadi. SiO_2 ning valent zonasida hosil bo‘lgan zaryad Si/SiO_2 chegara sohasida ushlanib qoladi. Bunday zaryadlarning to‘planishi ko‘pincha izolyatsion SiO_2 ning buzilishiga olib keladi, shuningdek, vaqt o‘tishi bilan ularning barqarorligini cheklash va radiatsiya qarshiligini kamaytirish orqali izolyatorli kremniy asosida hosil bo‘lgan qurilmalar parametrlariga ta’sir qiladi. Ushbu maqolada biz ion bilan o‘zgartirilgan kremniy-izolyatorli tuzulmalarni elektrofizik xususiyatlari tahlil etildi.

Kalit so‘zlar: polokristal, datchik, konsentratsiya, vodorod, nonokristalning interfeyslari, xemisorbtsiya, desorbsiya, metall modifikatori, dioksid plyonka, vodorod atomi, ish harorati, termal aylanish, sirt potensiali, dioksid plonkalar, kislorod ionlari.

ИССЛЕДОВАНИЕ СНИЖЕНИЯ ЭНЕРГОПОТРЕБЛЕНИЯ, РЕЖИМА ТЕРМОЦИКЛА И ВЗАИМОДЕЙСТВИЯ НОВЫХ МОДИФИКАТОРОВ ХАРАКТЕРИСТИК УСТРОЙСТВ НА ПОЛУПРОВОДНИКОВЫХ ДАТЧИКАХ

АННОТАЦИЯ

В области практического применения структур полупроводник-диэлектрик в приграничной области диэлектрика наблюдается накопление зарядов. Это серьезно влияет на рабочие характеристики электронных устройств, созданных на основе полупроводник-диэлектрик. Заряд, образующийся в валентной зоне S_iO_2, захватывается в области границы S_i/S_iO_2. Накопление таких зарядов часто приводит к разрушению изолирующего S_iO_2, а также влияет на параметры устройств на основе изолирующего кремния, ограничивая их стабильность и снижая с течением времени радиационную стойкость. В данной работе мы проанализировали электрофизические свойства ионно-модифицированных кремниево-диэлектрических структур.

Ключевые слова: полокристалл, сенсор, концентрация, водород, интерфейсы нанокристаллов, хемосорбция, десорбция, модификатор металла, диоксидная пленка, атом водорода, рабочая температура, термический цикл, поверхностный потенциал, диоксидные пленки, ионы кислорода.

STUDY OF THE ENERGY CONSUMPTION REDUCTION, THERMAL CYCLE MODE AND THE INTERACTION OF NEW MODIFIERS OF DEVICE CHARACTERISTICS ON SEMICONDUCTOR SENSORS

ANNOTATION

In the field of practical application of semiconductor-dielectric structures, accumulation of charges is observed in the dielectric boundary region. This has a serious effect on the operating characteristics of electronic devices created on the basis of semiconductor-dielectric. The charge generated in the valence band of S_iO_2 is trapped in the S_i/S_iO_2 boundary region. The accumulation of such charges often leads to the breakdown of insulating S_iO_2, and also affects the parameters of devices based on insulating silicon by limiting their stability and reducing radiation resistance over time. In this paper, we analyzed the electrophysical properties of ion-modified silicon-insulator structures.

Keywords: polocrystal, sensor, concentration, hydrogen, nanocrystal interfaces, chemisorption, desorption, metal modifier, dioxide film, hydrogen atom, operating temperature, thermal cycle, surface potential, dioxide films, oxygen ions.

Nowadays, the role of semiconductor physics is very important in the rapid development of modern science. In this regard, the role of effective solutions of the studies being studied is huge. in the study of modern devices, it is considered relevant to study the working principles of sensors based on thin polycrystalline SnO_2 films. for this, it is important to develop high-speed devices sensitive to external influences, to increase their reliability. enough problems were identified in the development of counters for the low concentration (4-8) $*10^3$ of samples taken in the field of semiconductors at the level of 0.4-0.8 volts, when divided into parts per million. $n_{H_2} \leq 10^3$ppm, where n_{H_2}- hydrogenconcentration.

The demand for such devices is increasing. The principle of operation of sensors for laboratory and medical purposes depends on the action of the electron impact of the substances included in the sample, taking into account that it depends on the control and speed of the devices.

H_2 is based on the phenomenon of reversible adsorption of gases on the SnO_2 surface.in the air atmosphere, in the operating temperature range of devices 180-500°C, a negative charge appears as a result of chemisorption of oxygen particles on the surface of polycrystalline SnO_2, its increase leads to a decrease in conductivity. the process of reducing the conductivity is associated with an increase in the energy barrier at the interfaces of SnO_2 nanocrystals. preventing the transport of electrons across the film, when interacting with O- particles, the barrier value on the surface of SnO_2 decreases and the conductivity of the sensor increases.Dissociation of molecular H_2O contributes to metal modifiers in SnO_2 structure.Russian scientists F.F. Volkenstein, I.A. Myasnikov, G. Korotsenkov, V. Brynzari, J. F. McAleer conducted the study of the gas sensitivity of the classic working SnO_2 in the center of many scientific researches in the world. Modern research on SnO_2-based sensors is aimed at reducing the transient shift of device characteristics during operation, reducing energy consumption, thermal cycling mode, and studying the effects of new modifiers [1].

Until now, the laws of oxygen chemisorption on the surface of SnO_2 have been determined. The relationship between the bending magnitude of the energy bands at the interfaces of SnO_2 nanocrystals and the effect of $e\varphi_{s0}$on the surface density of oxygen ions has not been sufficiently demonstrated.

According to these models, after the interaction of atomic hydrogen with O- ions, hydroxyl groups OH- are formed on the surface of SnO_2, which are then neutralized and desorbed [2-3].

In the process of formation, hydroxyl groups donate electrons to the conduction band of SnO_2. however, this idea has no theoretical basis. The charge state of the hydroxyl groups is determined by the electronic distribution function of the local energy levels in the band gap of SnO_2.

It occurs during the formation of particles. .it is shown that within the framework of the potential barrier mechanism, an increase in the negative charge density was observed on the surface of $e\varphi_{s0}$ due to the effect on conductivity. provides methods for determining the value $e\varphi_{s0}$, which is 0.49 eV for sensors based on SnO_2 at room humidity and T=623K for sensors based on thin SnO_2 films [8*, 9*] and 0.40 eV, with changed. however, the quantification $e\varphi_{s0}$ is described, based on a complex theory, the moisture content of the gas-air mixture has been observed to contradict the results of many studies. showed that it is necessary to take into account the strong influence of errors in the method of detection. $e\varphi_{s0}$ The method of determining the value $e\varphi_{s0}$ is the maximum time for hydrogen, the need is characterized by a large number of sensors to be placed in a large volume n_{H_2} temperature during high working hoursoften leading to device failure [4-5].

Existing models of the effect of metal modifiers on the behavior of devices do not fully explain the different dependence of the properties of sensors with different modifiers on H_2 concentration. humidity level of the gas-air mixture, it should be noted the weak level of research on the shift of the characteristics of the H_2 sensor, it is interesting to study the characteristics of the sensors in the Thermal mode during long-term use based on SnO_2. in this mode, it allows you to control the shift of the sensor characteristics, set to a specific gas and reduce the energy consumed by the sensors.

It is considered relevant to study the results of the research on the effectiveness of sensors based on H_2 SnO_2 thin films, modified with various metals, in dry and wet environments, in long-term working conditions and in thermal cycle mode. for this, develop an express method for determining the bending of energy bands $e\varphi_{sH}$ It is recommended to try using a polycrystalline tin dioxide film at the interfaces of SnO_2 nanocrystals. moreover, solving the kinetic equation of the neutral adsorption process turns the hydrogen atoms into the centers occupied by O_2 ions, a theoretical study taking into account that only a part of the formed hydroxyl groups is in the neutral state and desorbs from the SnO_2 surfacewas considered [6].

Hydrogen concentration, gas-air humidity effects of clean air mixtures + H_2 and the working temperature of the sensor according to the bending value of the energy zones $e\varphi_{s0}$H in the polycrystalline film at the interfaces of SnO_2 nanocrystals, $e\varphi_{sH}$is the surface potential in the atmosphere containing hydrogenwas studied taking into account.

As the main goal of the ongoing scientific research, the performance of sensors based on H_2SnO_2 thin films, modified with various metals, resistant to external influences when working in dry and wet environments, long-term working conditions and thermal cycle modeconsists of.

Study the properties of hydrogen sensors based on dioxide films modified with Pt⁄Pd, Au, Ag,Ag+Y, tin, the role of modifiers in a wide range of changes in ambient humidity and operating temperature of the devices, and the role of modifiers in the performance of hydrogen sensors. in the study of the laws of displacement of the characteristics of hydrogen sensors during long-term operation, based on thin films of tin dioxide, thermal cycle mode and methods of increasing the reproducibility of measurement results with instruments were developed [7].

Experimental work was carried out taking into account the effect of detecting low concentrations of hydrogen in the air, environmental humidity during long-term operation, and the shift of sensor characteristics. A model of dissociative adsorption of H_2 molecules was proposed and the H_2O SnO_2 surface and the corresponding kinetic equation were solved taking into account the presence of thin layers of tin dioxide on the surface of clean air + H_2 in moist clean air and gas-air mixture [8].

Three types of adsorbed particles (O-, OH, OH-), expression $e\varphi_{sH}$ for four series of sensors with different modifiers, experimentally established dependences $\boldsymbol{e\varphi_{s0}}$ and conductivity (G_0) air during heating humidity and temperature of sensors (T_2= 623, 673, 723 and 773 K) thermalwhen operating in cycle mode, $e\varphi_{sH}$dependencies H_2 are taken into account for hydrogen sensor responses. It is based on the proposed model of dissociative adsorption of H_2 molecules and the mechanism of action of H_2O different modifiers (P_t+P_d, Au, Ag, Ag+Y) shown. Sensors with samples of long-term shift of properties are determined based on thin films of H_2 SnO_2 with various metal modifiers, processes that determine the behavior of devices during long-term operation [9-10]. A proposed model of dissociative adsorption of H_2 molecules and H_2O.

It makes a great contribution to the understanding of the processes that occur during the interaction of gas particles with the surface of semiconductors on the SnO_2 surface. The presence of adsorbed O_2 particles should be taken into account when developing models of dissociative adsorption of molecules of other gases onto the SnO_2 surface. Also, the scientific significance of the work results is to suggest the mechanisms of influence of metal modifiers on the properties of H_2 sensors SnO_2 yupqa plyonkalarga asoslangan va uzoq muddatli ish paytida qurilmalarning vaqtinchalik siljishi masofasini aniqlash.

The possibility of determining the concentration of hydrogen n_$\boldsymbol{n_{H_2}}$ and two-way changes in the gas-air mixture moist clean air +H2 range $\boldsymbol{n_{H_2}}$ from 10 to $5\cdot10^3$ ppm was shown.

The maximum error in determination occurs when the concentration of H_2 is $\boldsymbol{n_{H_2} \leq 40\ ppm}$ and does not exceed 10%, and $\boldsymbol{n_{H_2} \leq 40\ ppm}$ – 5% recommendations are offered to optimize the work.

It is shown that the degree of dissociation of H2 molecules can be determined by choosing metal modifiers.

H_2 is investigated by O_2 on the surface of SnO_2, thereby controlling the sensitivity of the sensors to hydrogen and the humidity level of the gas-air mixture. Recommendations for reducing the drift of characteristics of hydrogen sensors based on tin dioxide thin films during long-term operation were developed. The choice of research methods is determined by the assigned tasks. The development of the model of dissociative adsorption of H_2 molecules is based on the application of the theory of electronic processes in the process of chemisorption of molecules and gas atoms on the surface of semiconductors.

Determining the bending value of the energy bands at the interfaces of SnO_2 nanocrystals results from the analysis of the expression of the conductivity of the sensor obtained within the framework of the widely used model of charge carriers crossing the barrier in polycrystalline semiconductors. a number of expressions used to analyze the experimental data were derived using solutions of the Poisson and electroneutrality equations, which are standard for semiconductor physics. Numerical values of quantities used to calculate and analyze the dependence of sensor properties, concentration of donor compounds, dielectric conductivity of polycrystalline tin dioxide films is taken from many literature sources. calculation and construction of correlations presented in the work were carried out using a personal computer and using standard numerical methods.

Analysis of the surface microstructure of SnO_2 films was carried out using an atomic force microscope. The research apparatus compared the general scientific results, formalizing and comparing the obtained results with the experimental data presented in the scientific publications published in the leading Russian and foreign publications.

In a research study on the effect of sensor drift, modifiers, and thermal devices on their properties, experimental research methods were used, prior to automated setups and experiments to measure sensor propertiessample storage and preparation methods were used. The sensor manufacturing technology is presented, which includes the following operations:

Continuous magnetron sputtering on a sapphire substrate in an oxygen-argon plasma of a Sn and Sb alloy target;

introduction of P_t/P_d, Au, Ag, Y modifiers into the mass and surface of SnO_2 films; photolithography; annealing; collection of samples.

four series of samples were prepared for experiments: Pt/Pd/SnO2: Sb (series 1), Au/SnO_2: Sb, Au (series 2), $P_t/P_d/SnO_2$: Sb, Ag, Y (series 3) and Ag/SnO_2: Sb, Ag, Y (series 4).

During the formation of SnO_2 films, antimony content in the target is 0.5%. To change the volume of SnO_2, pieces of matching metals were placed on the surface.

For all studied samples, the ratio of the surface area of metal S_{Me} particles and the area of the scattered part of the target S_{Sn} was the same and was 3·10−3. Ag in the volume of SnO_2 was placed on the surface of fragments of both metals in case of addition of Y, so $SAg/S_{Sn} = 3 \cdot 10^{-3}$ and $S_Y/S_{Sn} = 3 \cdot 10^{-3}$. Dispersed layers of catalysts on the surface of SnO_2 are applied using the same DC magnetron method [11]. If Pd is first deposited on p_t/p_d layers, before deposition of films with SnO_2 layer, sample size is 0.8×0.8 mm^2, sensitive layer - 0.3×0.3 mm^2. It is necessary to take into account that the thickness of films of the 1st series is 100 nm, 2nd series - 110 nm, 3rd and 4th series - 120 nm. The expression (1) for the excess barrier conductivity of the SnO_2 film in the polycrystalline thin film of tin dioxide was given

$$G_0(T,A) = G_{00}(T,A)\exp\left[-\frac{e\varphi_{s\,0}(T,A)}{kT}c\right]; \qquad (1)$$

Where A is the absolute humidity of the gas-air mixture; k– Boltzmann's constant; $G_{00}(T, A)$ – value determined by electrophysical parameters of SnO_2 and geometric dimensions of films

$$e\varphi_{s\,0}(T,A) = \frac{(eN_i(T,A))^2}{2N_d\varepsilon_r\varepsilon_0} + kT; \qquad (2)$$

2nd - donor input concentration SnO_2; ε_r - relative dielectric constant SnO2; ε_0 - electric constant. Desorption of oxygen ions is an inertial process that increases with increasing relaxation time. T decreases sharply [12], which can be used to determine $e\varphi_{s0}$(A) [12,13].

From the analysis of the conductance ratio $G_0(T_2)$ and $G_0(T_1)$, as well as the temperature dependence of the value, taking into account that G_{00} is in the selected temperature range, is constant in the SCR even with a rapid decrease in sensor temperature from N_d T_2 before T_1 Ni (T_2, A) that there was not enough time to changefor, this formula is used $e\varphi_{s0}$.

$$e\varphi_{s\,0}(T_2,A) = \frac{kT_1T_2}{T_2-T_1} In\left[\frac{G_0(T_2,A)}{G_0(T_1,A)}\left(\frac{T_2}{T_1}\right)^{0,75}\right] + kT_2; \qquad (3)$$

Based on the above, T_2 and the duration T_2 of the high-temperature part of the thermal cycle are chosen so that at the end of this part of the cycle, stationary values are established. $G_0(T_2, A)$ and $e\varphi_{s\,0}(T_2,A)$. T_1 should be significantly lower, but not less than 473 K, since $T_1 < 473$ K_2 to the surface of SnO_2 [14,15]

Chemisorption of molecular oxygen is characterized by another value$e\varphi_{s\,0}$. To ensure equality Ni (T_2, A) for some time T_1, the temperature change must be very fast.

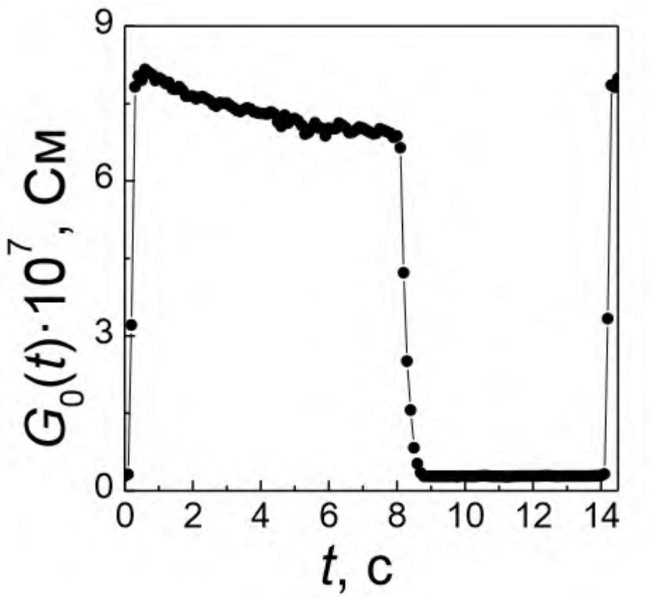

Figure 1 - Time dependence of the conductivity of the sensor in the thermal cycle mode.

The following parameters were selected for sensors of series 1: T_1= 473 K, T_2=673 K, T_2 and T_1 8 and 6 s, respectively. where the duration of the low-temperature part of cycle 1 is the temperature rise time T_1 before the temperature drop from T_2 was 0.2 s. (before T_2, T_1-0.7 s). to the time dependence of conductivity G_0(T) after a sudden increase in temperature T_1 before T_2 0.2< t <6.5 s a decrease in conductivity is observed due to a decrease in the surface density of adsorbed hydroxyl groups. An increase was observed after NOH. Stationary values of t > 6.5s are set in [3, 5, 12] centers where O ions are released due to adsorption.

$N_i(T_2)$, $e\varphi_{s0}(T_2,A)$ and $G_0(T_2)$ during rapid cooling of the sensor before T_2 in time T_1 8 < T < 8.7 s due to recharging of Ni(T_2) deep energy levels, O- for ions, decreases according to the expression G_0(1) and $e\varphi_{s0}$ (2) changes according to the formula (2). [In the interval 8.8 < t < 10 SG_0=const = G0(T1)] energy lines. $e\varphi_{s0}(T_1) = ([eN_i(T_2)]^2 /2N_d\varepsilon_r\varepsilon_0) +kT_1$. when bending, at t > 10 s, a slight increase in G_0(T) is observed due to the desorption of O- ions and the increase in the surface density of neutral hydroxyl groups.

The results of determination of $e\varphi_{s0}(T_2)$ at $A=6.1g/m^3$ for sensors based on $p_t/p_d/SnO_2$: Sb are presented in Table 1. Good reproducibility of $G_o(T_2)$, $G_o(T_1)$ and $e\varphi_{s0}(T_2)$ and values. $e\varphi_{s0}(T_2)$ in a series of 3 consecutive experiments. by reducing t1 from 6 to 2 s and t2 from 8 to 7 s in obtaining analysis results, the time of determining $e\varphi_{s0}(T_{2,}$ A) can be reduced without errors. The results of determining $ephs_0$ for other series sensors are presented in Table 2

Table I.
Properties of sensors based on Pt/Pd/SnO_2:Sb film $sn_{H2}=0$

Experience	$G_o(T_2)*10^7$, Cm	$G_o(T_1)*10^8$, Cm	$e\varphi_{s0}(T_2)$, eV
1	3.32	1.19	0.56
2	3.56	1.34	0.56
3	*3.43*	*1.27*	*0.56*

Table II.
$e\varphi_{s0}$value for series 1-4 sensors

Series	$e\varphi_{s0}(T_2)$, eV
Pt/Pd/SnO2: Sb (1)	0.56
Au/SnO2: Sb, Au (2)	0.4
Pt/Pd/SnO2: Sb, Ag, Y (3)	0.7
Ag/SnO2: Sb, Ag, Y (4)	*0.66*

In conclusion, an express method for determining the bending value of the ephs0 energy bands at the interfaces of SnO_2 nanocrystals in a polycrystalline thin film of tin dioxide, an analysis of time dependence taking into account the conductivity of the sensor in the thermal cycle modedeveloped on the basis ofinertial phenomenon during the desorption of oxygen ions from the semiconductor surface.The main role of the modifier particles (Pt/Pd, Au, Ag and Ag + Y) on the surface of SnO_2 is to set certain values for the dissociation levels of H_2 and H_2O molecules in the pure air + H_2 gas mixture. this ultimately leads to differences in electrical and gas sensitive properties of different series of sensors

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