Using the Semiconductors Materials of InSb-ZnTe System in Sensors for Gas Control

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Using the Semiconductors Materials of InSb-ZnTe System in Sensors for Gas Control

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Abstract. The samples of thin film semiconductor compounds InSb, ZnTe and solid solutions based on them were obtained by vapor deposition of components on a dielectric substrate in a vacuum, followed by annealing and their surface properties in CO, O_2 and NH_3 gas atmospheres were investigated. Identification of the samples was carried out by X-ray diffraction techniques. In the temperature range 253 ÷ 403 K and a pressure range of 1÷12 Pa the gas adsorption was measured by piezoelectric microbalance technique. In order to establish the basic regularities of processes flowing on samples surface in addition to the electrophisical were used Infrared and Raman spectroscopic measurements. The resulting addiction "surface property - composition" is extreme and have allowed to determine solid solution $InSb_{0,95}$-$ZnTe_{0,05}$ as the most sensitive to the presence of ammonia, selective and this sample exhibits a negligible oxidation of surface.

1. Introduction

Using of semiconductor sensors allows not only to do rapid detection and analysis of trace element in different technological environments, as well as check the harmful components of gas emissions from motor vehicles, chemical and petrochemical industries and the surrounding polluted areas.

In comparison to other methods of analysis, semiconductor sensors cause interest with their relative cheapness, compact size, ultra-high sensitivity and high reliability. Analytical sensor signal is caused by change in conductivity or other characteristics of the semiconductor surface during adsorption on it particles of different nature. Herewith, the sensor signal is proportional to the concentration of the particles.

Influence of adsorption processes on the resistance of the semiconductor material is explained by depletion of the conduction band relative to the electrons in the case of adsorption of oxidizing gases (O_2, CO_2, etc.), which leads to an increase of the energy barrier in the contact area of the particles and, as a result, the resistance of gas sensitive element increases. In other case the number of electrons at the surface of contact area increases in the case of gas adsorption with reducing properties (H_2, CO, etc.), the resistance of gas sensitive material is reduced accordingly.

Among the sensory analyzers are actively studied semiconducting oxides, but one of the most significant drawbacks is their influence on their characteristics in an open atmosphere, meteorological parameters such as temperature and humidity. Therefore, the attention of researchers to films and film structures A^3B^5, A^2B^6 compounds as devoid of such defects quite justified. Binary compounds and their solid solutions show themselves as promising materials for control of gas media [1–6].

Using the A^3B^5, A^2B^6 type compounds and solid solutions based on them as components of the sensor element provides a sensitivity to a broad range of toxic and chemically-active gases in the environment and gas emissions, but it should be noted that for each gas exists a fairly narrow temperature range, in which the sensitivity of the material to it the highest [7].

The basis of described semiconductor sensors are thin (250 nanometers) layers InSb, ZnTe and their solid solutions deposited on appropriate substrates (glass, potassium bromide, etc.). Selection of sensitive material for express diagnostics and control represents obtain samples of different composition, and studying the sensitivity of the electrical conductivity of the surface in adsorption different gases as well as the dynamics of the sensor signal formation.

2. Experimental

In the polycrystalline film samples InSb, ZnTe and their solid solutions in a concentration up to 20 mol.% ZnTe in InSb was prepared by depositing the vapor of components on a dielectric substrate in a vacuum with following annealing.

The radiographic studies were performed on BRUKER AXS Advanced D8 Powder X-ray Diffractometer instrument (CuKα-radiation, λ=1.54056 Å, T = 293 K) using the high-angle scattering technique [8].

The electron-microscopic studies were performed on JCM-5700 scanning election microscope instrumented with JED 2300 energy-dispersive analysis attachment.

Adsorption of CO, O_2, NH_3 in the temperature range of 253÷403 K and pressure range 1÷12 Pa was measured by piezoelectric microbalance method.

Electrical and IR and Raman spectroscopic measurements were used in addition to direct adsorption studies to establish the basic dependencies and mechanisms of interaction the surface with gases of different nature (CO, O_2, NH_3). IR absorption spectra were recorded on a spectrophotometer InfraLUM FT-02.

The experimental data, their reproducibility and accuracy was monitored by parallel measurements, and the use of computational algorithms of mathematical statistics.

3. Results and considerations

On the results obtained by x-ray diffraction studies films of binary components and solid solutions crystallized in a cubic structure. The presence and shift of corresponding lines in the diffraction patterns of thin films showed the formation of solid solutions InSb-ZnTe system. The dependence of the unit cell values and radiographic density is linear (figure 1), which is generally characteristic of the solid solutions.

The conducted optical researches allowed to determine the the band gap of the thin film samples (Eg), which has the following values: for InSb is 0.212 eV; $(InSb)_{0.95}$-$(ZnTe)_{0.05}$ is 0.285 eV; $(InSb)_{0.90}$-$(ZnTe)_{0.10}$ is 0.378 eV.

The specific surface conductivity with increasing amount of ZnTe in InSb up to 20 mol.% demonstrates a decrease exponentially due to the substitution of corresponding elements atoms in the crystal lattice of starting components (Figure 1). The format of the dependencies of the specific surface conductivity and the band gap of InSb-ZnTe system (Figure 1) allows us to conclude about the formation of solid solutions at these compositions.

The surface of the films A^3B^5, A^2B^6 and their solid solutions show significant heterogeneity, which is manifested in their contact with the gas media, and the microscopic study of surface films. Surface defects, defects in the crystal lattice, cluster formations ranging in size from a few to two or three dozen nanometers. However, the reproducibility of the synthesis conditions may reproducible physical and chemical properties of thin film samples. The presence and location of defects on the surface, their size, geometry of gas molecules affect the sensitivity and selectivity of thin film samples in relation to the different components of the gaseous media.

The magnitude of adsorption gases lies within $10^{-3} \div 10^{-5}$ mol/m^2. The experimental dependence of the adsorption on the temperature was allowed to specify the intervals reproducible operation of the film surface, which corresponds limits of a reversible chemical adsorption [8–9].

On the basis of the experimental relationships "adsorption value - thin film composition", samples with appreciable sensitivity to the studied gases were obtained. Namely, in the case of ammonia such adsorbent proved solid solution $InSb_{0.95}$-$ZnTe_{0.05}$. On a sample of this composition at the same external parameters value of adsorption all studied gases is two or three times lower compared with NH_3.

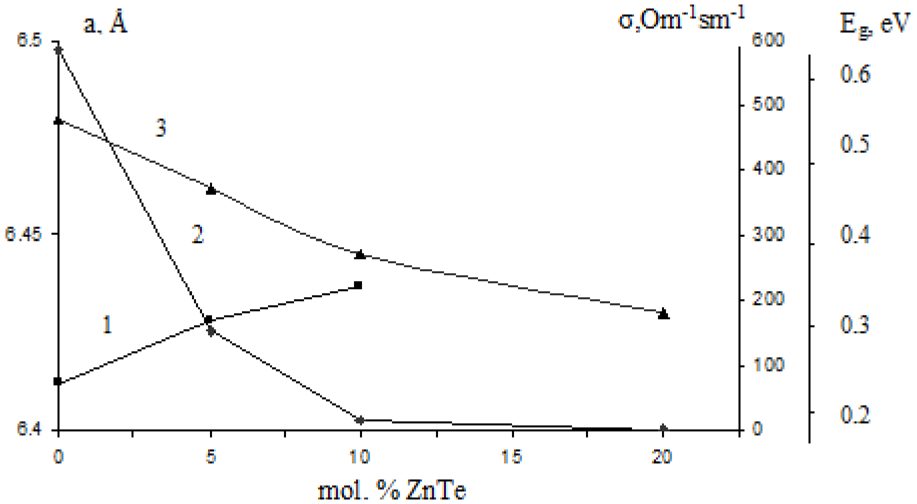

Figure 1. The dependences of the optical band gap (1), conductivity (2) and a cell period (3) of the system InSb - ZnTe components.

The analysis dependences of electrical properties of the studied sample surface from contact with the polluting gas is a necessary research step. Dynamics of changes surface conductivity relatively the vacuum in medium of CO, O_2 and NH_3 was studied by probe method on piezoelectric resonator (Figure 2, 3). The solid solution with composition $InSb_{0.95}$-$ZnTe_{0.05}$ in study showed the highest sensitivity of the surface characteristics to the presence of ammonia and carbon monoxide.

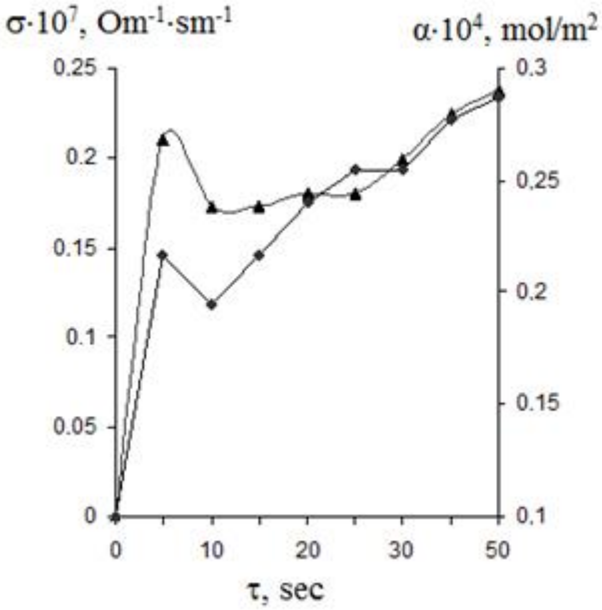

Figure 2. Dependences of the electrical conductivity of the surface (1) and the value of adsorption (2) for a contact time of $InSb_{0.95}$-$ZnTe_{0.05}$ sample in CO atmosphere (p = 5.3 Pa).

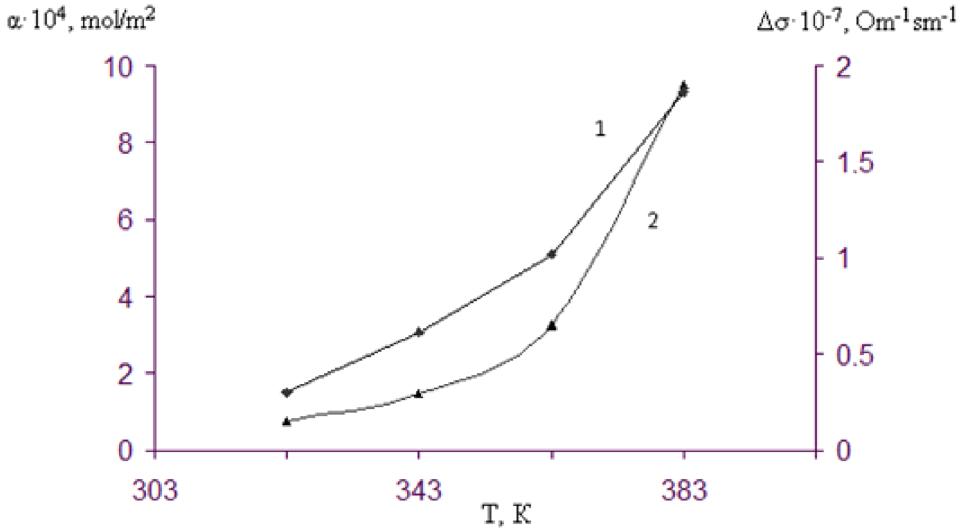

Figure 3. Dependences of the change the surface conductivity (1) and the value of adsorption (2) for $InSb_{0.95}$-$ZnTe_{0.05}$ sample in NH_3 atmosphere (p = 5.3 Pa).

That results correspond to the results of the adsorption measurements and confirmed their relationship for the semiconductor surface [8-9].

4. Summary

Thus, by method of evaporation in a vacuum the thin film samples of semiconductor A^3B^5, A^2B^6 compounds and solid solutions based on them with reproducible physical and chemical properties are obtained.

These samples are identified by X-ray diffraction techniques.

The surface adsorption, electrical and optical properties of InSb-ZnTe system components are studied.

Dependences of "surface property - composition" have an extreme view and reveals the optimum composition of the solid solution containing $InSb_{0.95}$-$ZnTe_{0.05}$, surface electrical conductivity of which is most strongly changes in ammonia, has more selectivity and a low surface oxidizability.

Due to possibility of regulating the surface properties combined with high surface activity and nano-scale irregularities present on the surface, the thin films of InSb-ZnTe system can be recommended as active elements for sensors.

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