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RESEARCH, TECHNOLOGY FOR OBTAINING AND ELECTRICAL CHARACTERISTICS OF SILICON-BASED SNO2 HETEROJUNCTIONS

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Abstract
In this work, the technologies for obtaining and electrical characteristics of heterostructures based on SnO_2 films deposited on silicon (Si) substrates are investigated. SnO_2 films were obtained by thermal evaporation in vacuum, as a result of which structures of the Ni–SnO_2–n–Si–Ni type were created. Volt-ampere characteristics (I-V characteristics), photoluminescence and infrared absorption of samples of the p-SnO_2/n-Si heterostructure were studied. It was shown that the direct current in optimal heterostructures is 50–60 times higher than reverse, and conductivity is due to the tunnel-recombination mechanism. Photoluminescent studies have revealed the presence of nanocrystalline phases on the surface of silicon and features of recombination processes. The prospects of using the obtained heterostructures as solar converters and gas sensors are noted.

Keywords. SnO_2 (Tin Dioxide), Silicon (Si), Heterostructure, Thermal Evaporation, Volt-Ampere Characteristics (I-VM), Photoluminescence, Infrared Spectroscopy, Solar Cells, Nanocrystalline Structures, Semiconductor Films.

Introduction

At present, electronic products for various purposes are used in many branches of industrial electrical engineering. The creation of highly sensitive, high-speed and high-precision devices and installations requires the development of new semiconductors. Having improved the methods for obtaining ZnO and SnO2 films, S.I. Rembeza [1] and his scientific school obtained thin layers on semiconductor substrates Si, Ge, GaAs, on the basis of which the high-efficiency solar cells, as well as by introducing atoms of various elements into the metal oxide layer, have shown the possibility of increasing their sensitivity to individual gases.

The purpose of this work is to develop a technology for producing SnO films$_2$, the study of the physical properties of the resulting heterostructures (p-SnO_2 /n -Si) influence their parameters, temperature, lighting and determination of the possibility of their practical application.

A heterojunction is a contact between two semiconductor crystals of different chemical composition, in which the crystal lattice of one semiconductor crystal passes into the crystal lattice of another semiconductor without disturbing the crystal structure.

Tin(II) oxide and silicon have unique properties. For tin oxide (SO2), the bandgap is 3.5 eV and for silicon (Si) 1.2 eV.

Combining such different semiconductor materials in one electronic device (creating heterojunctions) makes it possible to make the most of their properties.

A tin atom consists of a positively charged nucleus with a charge of +50, 50 protons and 69 neutrons, on five inhabitants there are 50 electrons (+ 50 Sn$)_2)_8)_{18})_4$. Total Tin Atom Electron Configuration 1S22S22P63S23P63d10 4S^{24P64d105S25P2}

The external energy level of the tin atom contains 4 valence electrons indicates that tin is characterized by the oxidation state of tin + 2, which is explained by the presence of two unpaired electrons (see Fig. 1).

Physical properties of SO2 are dark blue (almost black) crystals, tetragonal syngony, structure of the PvO type (*a=0,*3802 nm, *c=0,4837 nm, z=2,* the spatial group P4Z (nmm). At a pressure above 90 hPa (900 thousand atm), it turns into a rhombic modification (*a=0.382nm b*=0,361 nm, *c=0.430nm*, *z=2, space group Pm2n*))

Tin(II) oxide is an inorganic binary chemical compound of tin and oxygen, chemical formula S_{No2}, black and blue crystals. Tin oxide is a semiconductor whose type of conductivity depends on the impurities and the method of production.

SO2 condition, black powder. Molar mass, 134.71 g/mol. Tin (II) oxide is stable in air, amphoterene with a predominance of basic properties. Under normal conditions, it is a ductile, malleable and easily meltable shiny post-transition metal of silvery white light. Natural tin has 10 isotopes.

SO2 has the following thermal properties: melting point (at 80 kPa) 10800C, boiling point. 14250C, decomposition – 1976±10F, molar heat capacity 47.8 J/mol.K), thermal conductivity – 47.8 W/m.K.), vapor pressure 0±1 mmHg.

Tin (II) oxide is overwhelmingly used as a starting product in the production of other, usually divalent, tin compounds. It can also be used as a reducing agent and in the creation of ruby glass. In small quantities, it is used as an esterificator catalyst. Cerium(III) oxide with tin(II) oxide is used in lighting fixtures as a phosphor.

Tin dioxide is a compound that has a very wide range of practical uses; transparent and electrically conductive films for various purposes, gas sensors, catalysts, electrodes, functional composite materials, etc.

Methods and results of the experiment.

SnO Films$_2$ are applied to the n-Si substrate by thermal evaporation in vacuum 10^{-4} мм.рт.ст. при T ~ 1600 ^{0C}.

For removing the volt-ampere characteristics (I-VM) of SnO thin films$_2$ and heterostructures obtained on the basis of n-Si, a block diagram was used as in [2] When removing the I-V heterostructure, a shielded measuring cell was placed in a thermostat, which allows obtaining a stable temperature ranging from room temperature to 400 $^{0C.}$ Contact with the upper nickel electrode of the sample was carried out With a microprobe located on a micromanipulator inside the thermostat, the temperature of the thermostat, as well as the value of the voltage supplied from the power supply unit to the sample, is regulated by the control panel. With the help of the measurement unit, the temperature of the thermostat, voltages and current through the structures are determined.

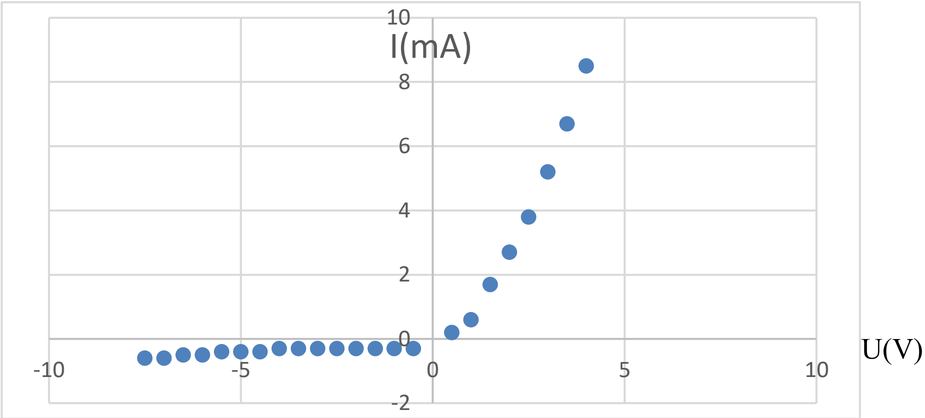


Fig.2. I-V structure of Ni-SnO2-n-Si-Ni for crystal film in the forward and reverse directions of the current.

In order to determine the conduction mechanism in Ni – SnO2 and create heterojunctions with a structure of the Ni-SnO2 - n - Si-Ni type on their basis, and their I-V were studied.
Figure 2 shows a typical I-V of one of the obtained heterojunctions. At voltages U≈5B in the best heterojunctions, the forward current exceeds the reverse current by 50-60 times (at T=300 K).
At direct displacements of U≤0.5 V, the dark current of heterojunctions obeys the known diode equation
I=I, $_s$(eU/e β ^{kt} –1), where the saturation current is Is=5*10-7A at T=300 K, and the current is the diode coefficient *β≈6-10*, which allows us to assume the tunneling-recombination nature of the direct current.
As the forward bias voltage, U≈2V, the forward bias dark current begins to follow a linear law
$I = \frac{U-U_o}{R_o}$
where the cut-off voltage is U≈2.0V, and the residual impedance is R0.
From the diode theories discussed above [3], that I-V can be either exponential or power-law ($I \sim V^n$). In the latter case, the exponent changes with a change in voltage: at small V's, Ohm's law holds, and when the voltage increases, I-V becomes quadratic (n=2).
Under some conditions, a "vertical" can be observed in the I-V of heterojunctions - a change in current by several orders of magnitude with a very small change in voltage.
SnO2 films were deposited on n-Si substrates by thermal evaporation of SnO2 in a vacuum $p \approx 10^{-4}$ mmHg. The temperature of the substrates varied within (50÷450)^{0C}
The rate of film formation at the evaporation temperature was (5-10) Å/s.
The calculated resistivity values of SnO2 films from linear I-V sections are 106-108 Ohm cm.

It is convenient to study the mechanism of electrical conductivity in thin films by analyzing the transverse conductivity of film sandwich structures[Fig.3]

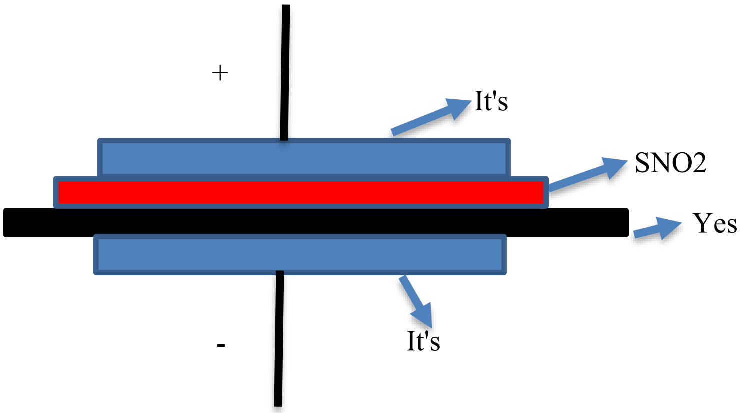


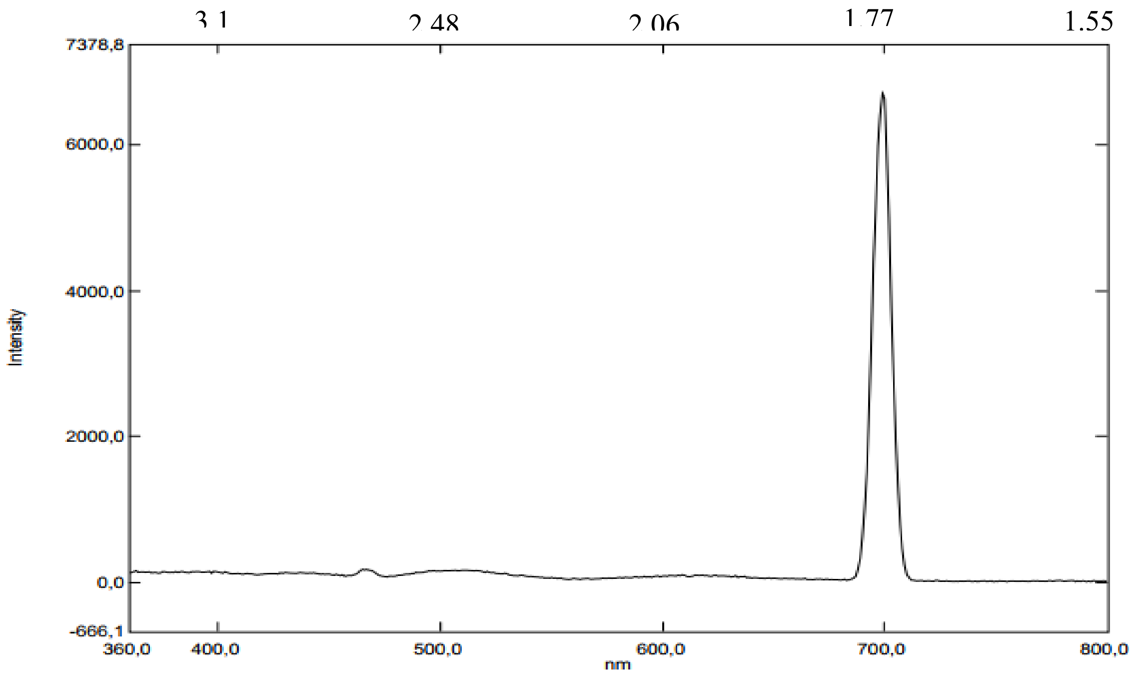
Рис.3.Структура Ni-SnO2-n-Si-Ni

Photoluminescence (FL) and IR absorption spectra.

The spectra of FL and IR absorption were taken in a spectrometer manufactured by SHIMADZU (Japan), the sensitivity range is (400 – 4000 $^{cm-1}$), the resolution is 4 $^{cm-1}$.

The photoluminescence spectra of the studied samples of the p-SnO2/n-Si heterostructure are shown in Figure 4, the spectral sensitivity range is 360 and 800 nm (3.1-1.55 eV) and covers a narrow intensity band at room temperature.

It can be assumed that in this case SnO_2 In the surface layer of silicon, they are centers of non-radiative recombination.



Rice. 4 Photoluminescence spectrum of the p-SnO2/n-Si heterostructure

Such a FL in the region of 1.75-2 eV is characteristic of porous silicon [5] and silicon nanostructures that include crystals - clusters with a size of 3-4 nm. The paper [5] shows the dependence of the intensity and position of the peak of photoluminescence of n-type porous silicon samples on its phase composition. It is noted that the position of the peak of photoluminescence varies within 1.75-2 eV, depending on the predominance of nanocrystalline or any of the amorphous phases in porous silicon.

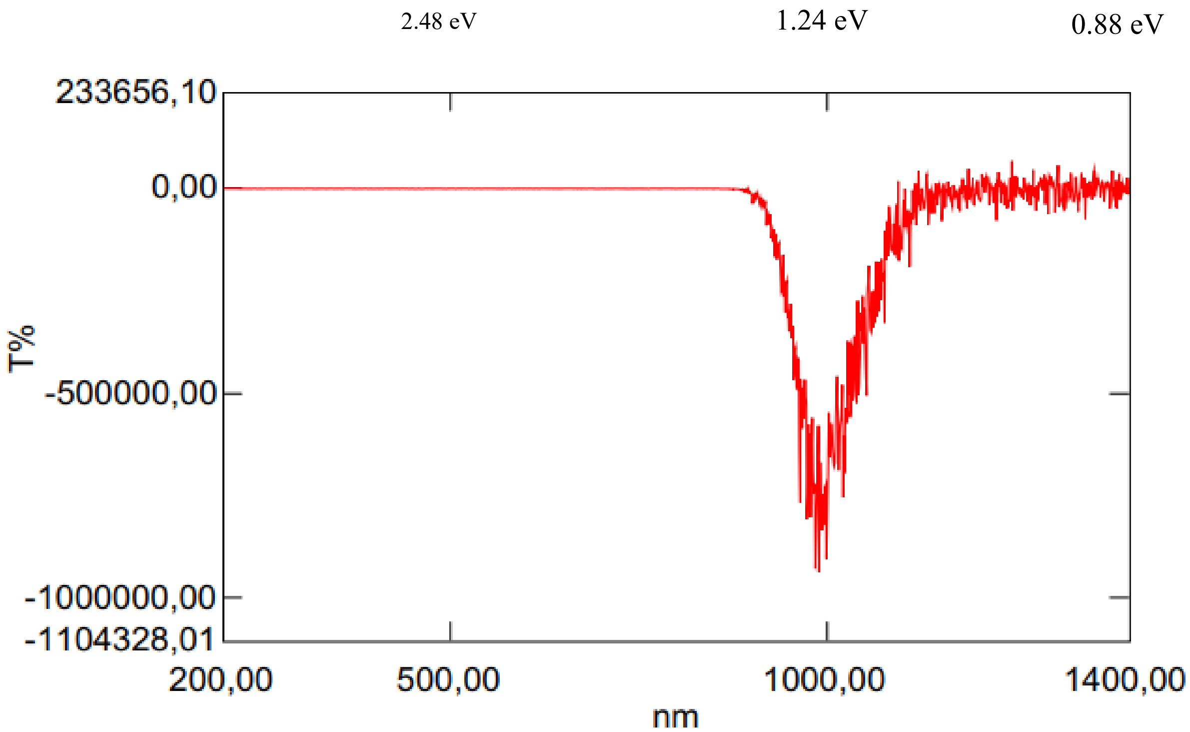


Fig.5. IR absorption spectra in p-SnO2/n-Si samples

In our case, the dependence of the intensity and position of the FL peak does not depend on the concentration of tin. It should be noted that metal tin nanoparticles can additionally create localization of permitted states near the ceiling of the valence zone of impurity centers, which can cause an increase in the Sn concentration of more than 3.0 at% [4], lead to a possible sweeping of the energy band of states below the Firmi level, which leads to an increase in the probability of thermal transitions and, as a result, to a decrease in the intensity of FL.

Measurement of the IR absorption spectra of p-SnO_2/n-Si samples (Fig. 4) showed that the absorption regions: the absorption band corresponding to SnO2 appears in the region of 1000 nm (1.24 eV), the presence of tin oxide atoms in the silicon surface leads to a noticeable increase in the intensity of the oxygen absorption peak.

It was found that with an increase in the proportion of tin oxide in p-SnO2/n-Si samples, the roughness of the film surface decreases. The possibilities of using the heterostructure of p-SnO2/n-Si in converters of solar energy into electrical energy have been determined.

Metal oxides SnO2 and ZnO have a bandgap of more than 3 eV and absorb light from the violet and ultraviolet parts of the solar spectrum well.

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