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MICROELECTRONIC SWITCH BASED ON SEMICONDUCTOR $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$

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Abstract. It has been found that the switching effect occurs in the In_2Te_3 semiconductor compound and solid solution crystals based on it. With this in mind, a thin-film microelectronic switch was created based on the $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ solid solution crystal, and its important characteristics were studied. It has been established that the switching mechanism in this semiconductor material has an electronic-thermal character and varies with temperature.

Keywords: solid solution, switching effect, thin films, volt-ampere characteristic.
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1 Introduction

In our previous works, we have established that a switching effect occurs in the In_2Te_3 compound and solid structures created on its basis (Permiakova, 2023; Hasanova, 1997; Zhang, 2024; Gasanova et al., 2014; Abilov & Hasanova, 2005). A similar effect is also present in indium monotelluride and crystals of solid solutions obtained on its basis (Sandeep, 2024; Abilov & Gasanova, 2003). The difference is that in this case the switching effect occurs at low voltages. In solid solutions with InTe, this effect is polar-dependent (Iskenderzade et al., 2000).

The process of resistance transition, corresponding to the electronic mechanism, occurs in the undoped In_2Te_3 compound in the temperature range of 77-200 K (Hasanova, 1997). In the temperature range of 200-350 K, the mechanism of the switching effect assumes an electronic-thermal nature.

Since one of the main goals is to expand the areas of application of materials containing indium tellurides, the synthesis of numerous homogeneous compositions was carried out. It was found that switching occurs in a crystal of composition $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$, on the current-voltage characteristic of which a residual differential resistance was observed. An electronic switch was constructed on the basis of this composition and some of its parameters were studied (Askerov et al., 2020).

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2 Experimental part

The semiconductor composition $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ was initially synthesized in polycrystalline form using a single-temperature synthesis technology and subjected to a homogenizing thermal treatment. The synthesis process involved the use of high-purity individual elements in quartz ampoules with a vibrating mixer at a temperature of 1200 K for approximately ∼8 hours. The obtaining of $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ solid solutions and their physicochemical properties are given in our work (Hasanova et al., 2005).

The thin film of this composition, which forms the active part of the electronic switch, was made in a vacuum using the hot-wall evaporation technique. The contact areas were also obtained using this technology. To design the switch, mask technology was chosen, which is widely used in the manufacturing of hybrid integrated circuits.

K-208 glass with a thin conductive transparent layer of SnO_2 was used as a substrate. The active material $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ with a thickness of ∼300 μm was deposited onto it by sputtering. A layer of In_2O_3 with a thickness of ∼10-15 μm was deposited on the surface of the active layer. A copper contact was formed on top of this layer to apply an electric field. At the ends of the structure, ohmic contacts were made of nickel in the form of thin layers, with a thickness ∼250 μm. One of these contacts is common, i.e. used for both signal pickup and voltage application. To protect the surface of the structure, it was coated with silicon dioxide SiO_2.

3 Results and discussion

It was established that with increasing temperature, the magnitude of the transition voltage decreases, and the voltage range corresponding to the residual resistance expands. The values of the operating current that generate low resistance were 10^{-4}-10^{-3}A. These values are limited by a series-connected load resistance and are not affected by temperature changes. The observed transition is polarity-independent in nature. According to the method described in (Goryainov & Abezgauz, 1970), the current-voltage characteristic was measured by applying single-length rectangular pulses. At this time, the duration of the pulses was $\tau = 10^{-4} \div 10^{-7}$ min, and their amplitude was ∼0-400 V. It has been determined from the $f = 100 \div 300Hz$ frequency research that there is no heating at room temperature.

At 353 K, as the pulsed current continues, the total current also increases. In the sample under study, the transition from a high-resistance state to a low-resistance state does not occur instantly, but gradually. This initial stage is determined by the switching delay time τ_{del} and specific transition time τ_{trans}. During the delay period, the voltage drop in the sample remains constant and matches the amplitude value of the pulses. At this time, a small current flows through the sample, the magnitude of which is determined by the initial resistance. With increasing temperature, the continuity of the delay period decreases, while the duration of the specific transition increases. These chemical processes occur according to the following laws with changes in temperature:

$$\tau_{del} = a_1 \exp(-a_2 T) \quad \text{and} \quad \tau_{trans} = b_1 \exp(-b_2 T).$$

Based on this change, it can be assumed that in a thin layer of $(In_{T}e_3)_{0.97}(MnTe_2)_{0.03}$, upon transition to a low-resistance state, the process of formation of a conductive pathway (channel, cord) for current flow occurs. When U>U_{trans}, the current cording has time-varying parameters. These parameters are mainly the current density, the cross-sectional area of the cord, and the temperature of the current cording region. Based on the simplified formula for the thermal balance of the cord current, i.e. based on the expression,

$$\frac{dT}{dt} = \frac{1}{C_p}\left[\sigma E^2 - \frac{\lambda}{l}(T - T_0)\right] \tag{1}$$

the time interval required to increase the temperature by dT can be characterized as follows:

$$dt = \frac{C_p dT}{\sigma E^2 - \frac{\lambda}{l}(T - T_0)}. \tag{2}$$

Here, λ represents the heat transfer coefficient specific to the thin film material, σ denotes the electrical conductivity of the material, I is the current through the sample, E represents the intensity of the electric field acting upon the sample, and C_p stands for the heat capacity of the thin film material. This formula serves as a qualitative indicator of the influence of temperature and electric field intensity on the delay time of the transition in practical terms (Gasanova et al., 2014).

It should be noted that at this time the speed of the formation of the current cord also increases. The augmentation of τ_{trans} with an increase in temperature signifies that the current flow through the thin film follows the electronic mechanism.

Branching of the current paths can be observed when the value of the voltage applied to the thin layer reaches a critical level. The reason for the formation of a current cord in the thin film under study may be the presence of defects in the crystal structure and drift barriers to current.

As a result of studying the temperature dependence of charge carrier mobility in a thin film $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$, it was found that the mobility decreases with increasing temperature. In other words, the influence of electronic phenomena is felt here too. Evidence of the sufficient influence of electronic processes on the switching mechanism is a decrease in the delay time as a result of the influence of the applied field.

As a result of the comparison, it became clear that in bulk crystals such a decrease is less pronounced than in a thin layer. The rate of decrease in delay time in a thin layer with a thickness of d=300 μm is measured in $tg\alpha$=2.1$\cdot 10^{-3}$ cm/degree. It can be assumed that the factor that changes the parameters of the thin layer and causes the transition is Joule heat.

Analysis of the oscillograms of the corresponding current pulses showed that the heat released at a certain point in time cannot ensure an increase in the current with constant heating and even in the absence of heat transfer. When heated, the change in the electrical conductivity of the sample with temperature and the action of an electric field can be estimated as follows:

$$\sigma(T, E) = \sigma_0 \exp\left[\frac{\Delta E}{k_0 T} + \frac{aE}{(T^* - T_0)}\right]. \tag{3}$$

ΔE denotes the activation energy of electrical conductivity, a represents the coefficient illustrating the variation of sample dimensions with temperature, and T^* is the critical temperature, which is determined experimentally from the dependence $\ln U_{trans} \sim T^{-1}$.

As a factor confirming a sufficient proportion of electronic processes in the semiconductor material under study during the transition, we can indicate a linear change in the dependence $\ln t_{del} \sim E/E_{crit}$ at high temperatures, where E is the effective external electric field and E_{crit} is the critical electric field.

Therefore, based on the results derived from the influence of temperature and voltage on a thin layer of $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$, it can be inferred that the mechanism governing the resistance transition in this material aligns with that observed in the In_2Te_3 compound (Tsennydin, 1985). It is of an electronic nature and not of a thermal type, undergoing a transformation to a thermal-electronic nature.

Fig. 1 illustrates the volt-ampere characteristic of an $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ thin film. The degree of deviations in the parameters of these characteristics was found to be less than 10%.

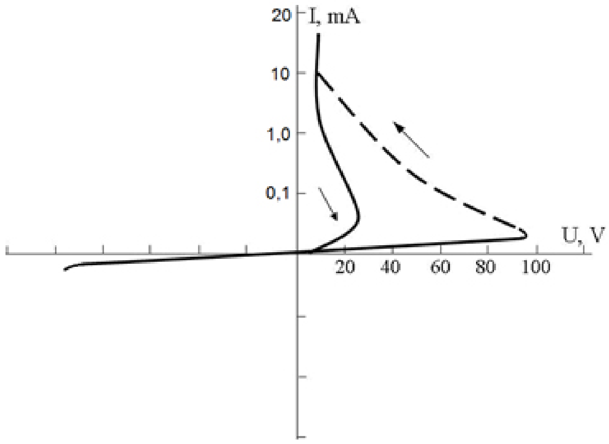

Figure 1. Volt-ampere characteristics of $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ thin film

Notably, at elevated values of the electric field, a switching effect is observed in the material, causing the sample to transition from a high-resistance state to a low-resistance state. Considering the occurrence of such a phenomenon in a thin film, a construction of a thin-film electronic switch was implemented utilizing the $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$ solid solution (Abilov et al., 2023). Fig. 2 illustrates the structure of the electronic switch with an active layer of $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$.

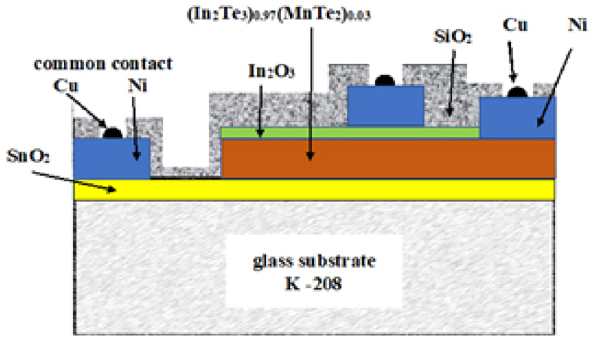

Figure 2. Cross section of the microelectronic switch with an active layer $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$

The operation of the switch is carried out by applying the corresponding potential to the active layer. Some parameters of the electron switch are as follows: switching time is approximately $\sim 10^{-4}$ seconds, switching potential is around $\sim$98 V, the size of the contact areas is approximately $\sim 2 \times 2mm^2$, and the dimension of the active layer of the switch is $5 \times 5mm^2$.

4 Conclusion

Based on the switching effect in $(In_2Te_3)_{0.97}(MnTe_2)_{0.03}$, the microelectronic switch was designed and its main parameters such as signal transition time, transition potential, and geometric dimensions of the active layer were calculated. Such prepared electronic switches can be used in various simple electrical circuits, including medical electronic devices.

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