Influence of external factors on the electrical conductivity of $Bi_2Te_{2.5}Se_{0.5}$

G. M. Ahmadov [a], H. B. Ibrahimov [a], M. A. Jafarov [b,c*]
[a]*Institute of Physics of Azerbaijan NAS, Baku, Azerbaijan*
[b]*Baku State Universitu, Baku, Azerbaijan*
[c]*"Composite Materials"Scientific Research Center, Azerbaijan State University, Bacu, Azerbaijan*

The mechanism of intrinsic and impurity electrical conductivity of semiconductors based on $Bi_2Te_{2.5}Se_{0.5}$ has been elucidated. The nature and reasons for the dependence of electrical conductivity on various external influences are considered. In this case, the temperature dependence of electrical conductivity, light absorption and photoconductivity of $Bi_2Te_{2.5}Se_{0.5}$ were used as external influences. And also the influence of the electric field was studied and it was found that in this case the value of the critical energy is $10^7 V/m$.

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1. Introduction

From the formula $\gamma=\gamma_n+\gamma_p=en\mu_n+en\mu_p$ it follows that the value of the specific conductivity is determined by the concentration of free charge carriers and their mobility. The mobility of charge carriers μ, determined primarily by their effective mass, velocity and frequency of collisions with sites and defects of the crystal lattice, generally weakly depends on temperature. Therefore, the nature of the temperature dependence of the electrical conductivity of semiconductors is mainly influenced by the concentration of charge carriers. Let us consider this effect on an example of a semiconductor $Bi_2Te_{2.5}Se_{0.5}$ doped with a donor impurity, the main carriers of which are electrons. We will assume that $\mu_n = const$ [1-5].

At a temperature tending to absolute zero, all electrons are bound to atoms, there are no electrons in the conduction band, and the conductivity is zero. If, due to external energy, the temperature of the semiconductor is increased, then some electrons will begin to pass into the conduction band. First of all, this will affect the weakly bound electrons of the impurity atoms, which require energy much less than the activation energy of their own electrons to enter the conduction band. Consequently, with an increase in temperature, the concentration of charge carriers and conductivity will increase. Simplistically, this dependence can be described by the expression

$$\gamma=\gamma_0 e^{-(W/2kT)} \tag{1}$$

where γ_0 - is a constant coefficient.

Taking the logarithm of this expression, we get

$$ln\gamma=ln\gamma_0-(W/2kT) \tag{2}$$

those $ln\gamma$ increases linearly with decreasing $1/T$.

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[*] Corresponding author: exmedovqurban@rambler.ru
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With a further increase in temperature, the impurity will be depleted, i.e. all valence electrons of the impurity will pass into the conduction band, after which the conductivity will cease to increase. The conductivity will remain constant until the temperature rises so much that the energy of its own electrons exceeds the band gap. Then the concentration of charge carriers will begin to increase sharply due to their own electrons passing into the conduction band. Due to the fact that the concentration of intrinsic atoms is several orders of magnitude higher than the concentration of impurity atoms, the value of intrinsic electrical conductivity will be significantly higher than the value of impurity, and the contribution of the latter to the total electrical conductivity will be negligible [6-9]. At high tempγeratures, semiconductors are close to conductors in terms of conductivity. Having studied the dependence $ln\gamma=f(1/T)$, one can experimentally determine the semiconductor band gap and the ionization energy of impurities. When particles of light energy pass through a semiconductor - photons are absorbed by electrons and atoms of the crystal lattice. The degree of absorption of electromagnetic energy is characterized by the absorption coefficient α, the reciprocal of which is equal to the thickness of the semiconductor layer, when passing through which the light intensity decreases by $e=2.72$ times [10-12].

In the absence of an external electric field, the equilibrium charge carriers present in the semiconductor at a given temperature move randomly in different directions. Therefore, the average speed of their movement is zero. If an external electric field with intensity E is applied, then a directed motion is superimposed on the chaotic thermal bias of charge carriers, i.e. an electric current is generated in a semiconductor. If the conductivity is constant, then with increasing field strength, the current density will increase linearly. This is exactly the case in a semiconductor, but only as long as the field strength does not exceed a certain critical value. With a further increase in the strength, the conductivity of the semiconductor begins to increase. Consequently, according to $\gamma=\gamma_n+\gamma_p=en\mu_n+en\mu_p$, the concentration or mobility of charge carriers should increase. The reasons for the change in the concentration of charge carriers are considered [13-17].

2. Experimental details

With increasing concentration, the value of γ increases. At the same time, due to an increase in the interaction between impurity atoms, the ionization energy of impurities decreases. At a sufficiently high concentration of impurities, the impurity level, expanding into the band, merges with the conduction band, i.e. $W = 0$. Consequently, even at low temperatures, all the valence electrons of the impurity are of the conduction electron, and the concentration of the impurity charge carriers is independent of temperature. This semiconductor is called a degenerate impurity semiconductor. The concentration of impurities has no effect on the value of intrinsic conductivity.

The temperature dependence of the conductivity is influenced by the inconstancy of μ, the presence of several types of impurity defects in the semiconductor, and other reasons. A slight decrease in conductivity with an increase in temperature to *100-300K* is caused by a decrease in the mobility of charge carriers due to more frequent collisions with atoms of the crystal lattice.

Having absorbed a photon, the electron goes to a higher energy level. And since there are free levels in an intrinsic semiconductor only in the conduction band, only photons with energy greater than the band gap ΔW will be absorbed. Since the band gap for different semiconductors varies from *0.1* to *3eV*, then the threshold length of the absorbed light can lie in different parts of the spectrum: infrared, visible, ultraviolet. By examining the dependence of the absorption coefficient on the wavelength, it is possible to determine the band gap of the semiconductor.

By the value of the band gap $\Delta W=0.2eV$ for $Bi_2Te_{2.5}Se_{0.5}$, we obtain

$$\lambda=hc/\Delta W=6.2\mu m \tag{3}$$

Thus, $Bi_2Te_{2.5}Se_{0.5}$ will only absorb light with a wavelength less than $6.2\mu m$. The dependence of the absorption coefficients on the wavelength of incident light is shown in Figure 1. The maximum wavelength of incident light absorbed by a semiconductor is called long-wavelength.

The considered transition of electrons due to absorption of photon energy from the valence band directly to the conduction band is called a direct transition. But this is not the only absorption mechanism. An electron can absorb a photon with energy lower than ΔW, if it receives the missing energy due to thermal vibrations. This transition of an electron to the conduction band is called indirect. The energy of photons can also be absorbed by the crystal lattice itself, electrons of impurities, free electrons. But the degree of absorption of electromagnetic energy in these cases is relatively small. So, the absorption of light leads to the appearance in the semiconductor of additional, in addition to those available at a given temperature, no equilibrium charge carriers. Consequently, the electrical conductivity of the semiconductor will increase.

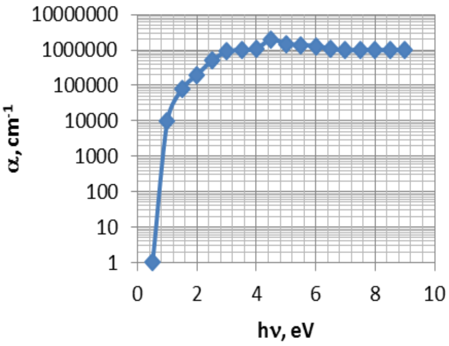

Fig. 1. Intrinsic absorption spectrum of $Bi_2Te_{2.5}Se_{0.5}$.

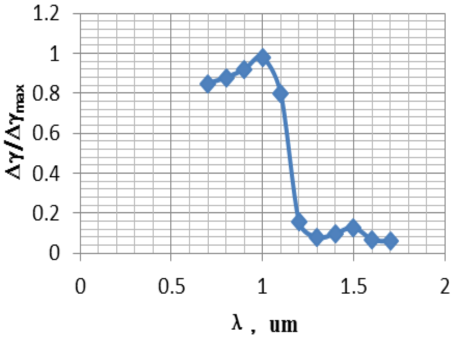

Fig. 2. Spectral characteristic of the relative photoconductivity of $Bi_2Te_{2.5}Se_{0.5}$.

The spectral characteristic of photoconductivity, in addition to the considered long-wavelength decay, also has short-wavelength decay. This decline is explained by the fact that with an increase in the energy of the incident light, the energy of free electrons in the thin surface layer of the semiconductor increases, and the total concentration of electrons decreases. Therefore, photoconductivity in specific semiconductor materials is usually observed in a rather narrow wavelength range.

With an increase in the irradiation intensity, the amount of free charge carriers in the semiconductor will increase. But at the same time, the intensity of the reverse recombination process will increase until a dynamic equilibrium is established between the processes of generation and recombination of charge carriers. The dependence of photoconductivity on the irradiation intensity is shown in Figure 3.

The process of exposure to light on a semiconductor is reversible. After termination of irradiation, the semiconductor conductivity will return to its previous value. But the time required for the recombination of the no equilibrium charge carriers that appeared as a result of irradiation for various semiconductors ranges from nanoseconds to several hours. This process is called photoconductivity relaxation. To characterize it, the effective lifetime of no equilibrium charge carriers is introduced, during which the carrier concentration decreases by a factor of *e*. The average distance that charge carriers have time to move in time τ is called the diffusion length of minority charge carriers. When obtaining semiconductor materials intended for high-frequency devices, the values of τ and l must be reduced. For this, the semiconductor is doped with impurities that create deep energy levels in the forbidden band.

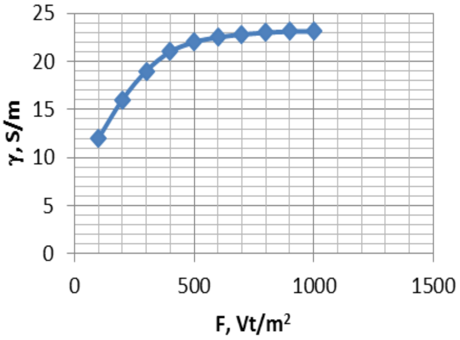

Fig. 3. Graph of the dependence of the photoconductivity of $Bi_2Te_{2.5}Se_{0.5}$ *on the irradiation intensity.*

A free electron, having passed a distance l in a semiconductor under the action of an electric field, increases its energy by the amount elE. At $E>E_{critical}$ this energy turns out to be enough for the collision of an electron with atoms to lead to ionization, additional charge carriers, in turn, are accelerated by the field and generate new free carriers. This process is called impact ionization of a semiconductor.

With an increase in E to a certain value, the process of increasing the concentration of charge carriers will be partially compensated by the reverse process of recombination. At $E>E_0$, recombination can no longer compensate for the generation, the concentration of charge carriers and the current density increase like an avalanche, a large amount of heat is released, and a breakdown occurs.

The critical energy value is $10^7 V/m$. Such a value of the field strength can arise even at low voltages in thin semiconductor layers. In the production of semiconductor devices, this leads to a limitation of the minimum thickness of the semiconductor layers, makes it necessary to increase the resistivity of semiconductor materials.

Impact ionization is not the only reason for the increase in the concentration of charge carriers with increasing electric field strength. Due to the potential energy possessed by an electron in an electric field, due to its wave nature, it can leak through the forbidden zone and go into the conduction band. This effect is called tunneling. It occurs when $E=10^9 V/m$.

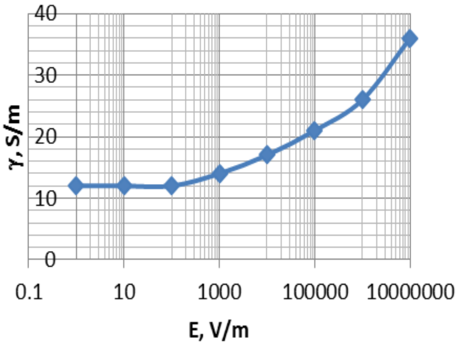

Fig. 4. Graph of the dependence of the conductivity of $Bi_2Te_{2.5}Se_{0.5}$ *on the strength of the external electric field.*

3. Discussion and conclusions

With increasing temperature, the conductivity of semiconductors increases, i.e. they have a negative temperature coefficient of resistance. This dependence is used to create semiconductor primary temperature converters. For this purpose, $Bi_2Te_{2.5}Se_{0.5}$ semiconductors with a high γ value are used. Analysis of the dependence $\gamma = f(T)$ once again confirms the possibility of controlling the properties of a semiconductor by introducing impurities into it. But this control is possible only in the area corresponding to impurity electrical conductivity.

The dependence of the electrical conductivity of semiconductors on lighting is used to create various photosensitive devices operating in a wide range of wavelengths. The use of solid solutions of several semiconductor materials and the introduction of the necessary impurities makes it possible to manufacture devices with the required absorption spectrum, inertia, and other characteristics. Other mechanisms for an increase in the concentration of charge carriers in strong electric fields are also possible. All of them at the final stage lead to breakdown of the semiconductor. In contrast to concentration, the mobility of charge carriers with an increase in the electric field strength can both increase and decrease. The possibility of a slight decrease in the mobility of charge carriers in strong electric fields leads to the appearance of a section with a negative resistance on the current-voltage characteristic, which makes it possible to create microwave semiconductor generators.

Conclusions

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