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Temperature dependence of the optical absorption and electroabsorption in chalcogenide glasses based on barrier-cluster model

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In paper the problem of influence of temperature on the optical absorption and electroabsorption in chalcogenide glasses in region of exponential tails is analysed from point of view of barrier-cluster model. The barrier - cluster model assumes that there are microregions – closed clusters - in a glass separated from each other by the potential barriers which restrain (restrict) a transport of charge carriers at the bottom of the conduction (or valence) band. At the same time barriers influence an optical absorption and electroabsorption to a great extent.

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1. Introduction

Investigation of physical properties of chalcogenide glasses has begun many years ago by Kolomiets with coworkers. Their works have initiated a gradual growth of interest in these glasses as well as in non crystalline conductors. Later on extensive investigation has offered new knowledge concerning these materials [1-2]. In this early stage knowledge of experimental character has been dominated.

Non-crystalline solids represent an extremely wide variety of materials because they also include many component systems, in which the stoichiometric abundance of particular substances is not needed. Moreover, they are mostly metastable systems, and their metastable state depends on sample preparation [3-7].

Chalcogenide glasses have been recognized as promising materials for infrared optical fibers and elements. They have found applications in xerografy, switching and memory devices, photolitography processes and in the fabrication of inexpensive solar cells, and more recently as reversible phase change optical recorders. The addition of an impurity has a pronounced effect on conduction mechanism and structure of glasses and this effect is very different for various impurities. This enables to prepare materials in a broad spectrum of properties [1-9].

The physical phenomena in non-crystalline material are very complex and experimental research in this area is very extensive. It calls for theoretical analysis, but a generaly accepted model of a non-crystalline semiconductor does not exist yet [1-9]. The problems of structure, mechanism of electric conduction and nature of many optical phenomena stay still open. The mechanism of exponential tails formation, the origin of optical absorption or the law of electroabsorption and luminescence have been impossible to understand up to day. It was expected that optical measurements will offer important information about electronic spectrum of these materials. The problem proved to be much more complex when compared with crystals and is still covered by impenetrable secrets.

In the first introductory part of the paper we would remind basic knowledge about chalcogenide glasses, fundamentals of the barrier–cluster model as well as known works on explanation of optical absorption and electroabsorption based on the barrier-cluster model. In the second part of the article new results are presented, which are related to the explanation of the temperature dependance of optical absorption and electroabsorption in the frame of the barrier-cluster chalcogenide glass model.

1.1 Optical absorption

In most crystalline solids, optical absorption is characterized by a sharp edge at the margin of the absorption band. Its position corresponds to the optical width of the forbidden band. However, the situation is different in the case of non-crystalline semiconductors. The absorption band near its border is smeared out and it creates a tail that extends deep into the forbidden band. Its profile is exponential as a rule. The exponential tails at higher temperatures tend to fit Urbachs formula. An inclination of the exponential tails decreases with increasing temperature. At low temperature the tails are parallely shifted. An important property of the exponential tails of the optical absorption is that they go deep inside a forbidden band of a semiconductor.

Few attempts on explanation of the exponential tails origin and their properties can be found in the pioneering work of Mott and Davis [1]. Some investigators consider a tailwise distribution of the state density in a forbidden band of a non crystalline semiconductor. In some other models it is assumed that in the forbidden band there are energy levels which belong to different type of centers. We do not know any substantial experimental data supported (or rebutted) this last assumption. Therefore, the existence of such energy levels becomes doubtful [9]. In some works the rise of absorption exponential tail is considered (treated) as a consequence of exciton energy levels. These levels in an inner stochastic force field of a non crystalline semiconductor may transform into the shape of a tail.

In work [1] one can find apart from various views on the exponential tail problem moreover arguments which doubt particular explanations. No one from current theories explaining (of) the exponential tails origin satisfy physical community in so much that it can be taken for (trustworthy) responsible in the explanation of current phenomenon. Therefore, the exponential tails problem stays still open.

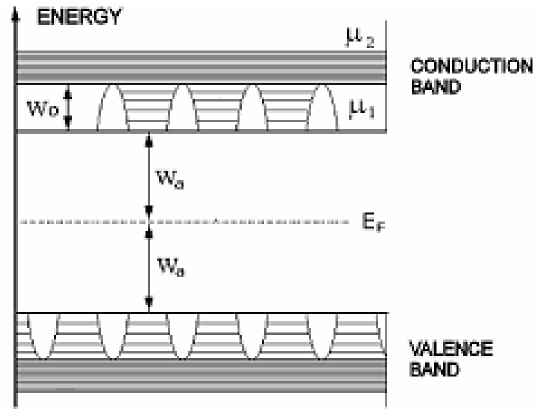

Fig. 1. Electronic spectrum of chalcogenide glass.

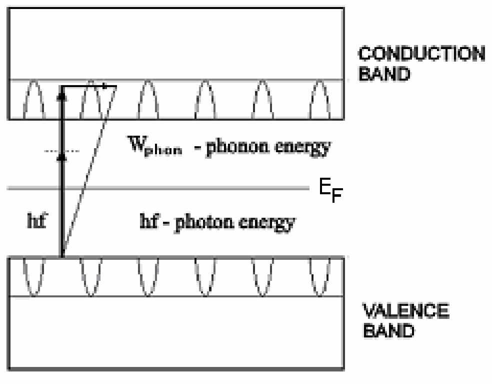

Fig. 2. Optical absorption at higher temperatures.

1.2 Electroabsorption

Experiments were done by Kolomijec with co-workers [10] in which was observed the influence of strong electric field on optical absorption in chalcogenide glasses for the first time. They observed electroabsorption in amorphous semiconductor As_2S_3. In their study [11], results of measurements of absorption coefficient as well as changes of the coefficient caused by electric field are presented for semiconductors As_2Se_3, $(As_2Se_3)_{0.95}(As_2Te_3)_{0.05}$, $(As_2Se_3)_{0.91}(As_2Te_3)_{0.09}$. The measurements were carried out in the field of 10^7 Vm^{-1}. Similar results for the material $(As_2Se_3)_{0.95}(As_2Te_3)_{0.05}$ are presented in [12]. Robertsa et al. [13] the studied electroabsorption in selenium. The problem discussed later in [14,15]. The experiments [16,17] show that a relative change of optical absorption by electroabsorption is directly proportional to the quadrat of the intensity E of electric field, so that $\Delta\alpha/\alpha \sim E^2$. In the works [18,19] are described the measurement methods of electroabsorption.

Electroabsorption in chalcogenide glasses at the edge of optical absorption tends to be interpreted as Franz-Keldysh effect [20,21] in conditions of fluctuating electrical potential [22-23]. In other cases the electroabsorption is considered to be the consequence of degeneration of an electron energy level – for instance of excitons level - in a fluctuating inert electric field [14, 24-25]. According to [26] due to considerable deficit of photon energy, the electroabsorption could be connected with electron transition between localized states. The work [27] explains the influence of the electric field on optical absorption by a density change of localized states in the gap of a non-crystalline semiconductor under the influence of the electric field

1.3 Barrier-cluster model

The barrier-cluster model assumes that an amorphous semiconductor consists of microscopic regions - separated from each other by potential barriers [28-38]. Microregions are identical with closed clusters in this model. The model comes out from idea that the other low-dimensional covalent systems, as e.g. chalcogenides could present special configurations similar to fullerenes or nanotubes – clusters [39,40].

Cluster structures of chalcogenide glasses and their physical properties were studied in works [41, 44] using computer's methods. Closed clusters enable explanation of very important properties of chalcogenide glasses as a deficit of *EPR* signal as well as the *X*- ray examination results.

The barriers restrict the transition of low energy conduction electrons from one region to the other. Such electrons behave between barriers in particular regions of material in a similar way as electrons in a crystal do. The potential barriers can be depicted inside the conduction (respectively valence) band of an amorphous material, separating individual localized energy states at the edge of the band (Fig. 1).

The electron levels between barriers, due to the small dimensions of the microscopic regions, exhibit a distinct discrete character. At the lower margin of the conduction band, a sub-band with carriers of low average mobility (μ_1) is created. The states with energy above the peaks of barriers are delocalized. They create a sub-band with a high average mobility (μ_2). Thus, it is clear that the activation energy of an amorphous material as a whole becomes a highly questionable quantity. At higher temperatures, it is determined substantially by the height of the potential barriers. At lower temperatures, however, the transport in a region below the peaks of barriers may dominate, and the corresponding activation energy will obviously be low. Quite a similar situation occurs at the edge of the valence band.

1.4 Optical absorption from point of view of barrier-cluster model

1.4.1. The region of high temperatures

The starting point of the following considerations on the basis of the barrier-cluster model is the assumption that the potential barriers in non-crystalline semiconductors create favourable conditions for a distinct absorption of light, with phonons participating in the energy exchange [28-30]. We assume that an electron in an optical transition accepts not only the energy hf of a photon but also the phonon energy W_{phon} (Fig.2). Thus, the whole energy accepted is $hf + W_{\text{phon}}$, where W_{phon} is the energy acquired from a phonon "field". The quantity hf is positively determined by the wavelength of radiation, while W_{phon} has a statistical character.

In principle, a photon can be absorbed only when the energy of the electron is sufficient to cause a transition of the electron into the conduction band. It should be taken into account, however, that optical transitions on the energy levels lying just below the tops of barriers will dominate at higher temperatures. In this case, the probability of transition within a single localized region is low. The levels in adjacent microregions offer more possibilities of combination. However, they are connected with tunneling through barriers. Under these assumptions, the transitions to levels just below the barrier peaks will be more probable for two reasons. The transitions on lower levels will be restricted considerably by a small tunneling probability. The second reason rests on strong electron-phonon interaction caused by the barriers.

The number of electrons that can acquire such energy from a phonon field depends on temperature. The amount of electron transitions when irradiating material by "low energy" photons (and thus, also the coefficient of optical absorption α) is directly proportional to this number. For the absorption coefficient it can be written $\alpha \approx \exp(hf/2kT)$ or, for a particular (constant) temperature

$$\text{In}\alpha = hf + \text{const}, \qquad (1)$$

which is a mathematical expression of an exponential tail of optical absorption [28,30]. However, the slope of the tails is also temperature dependent. Formula is of the same kind as the Urbach's formula. It explains the temperature dependence of the slope of exponential tails at high temperatures.

1.4.2. The region of low temperatures

At low temperatures, the absorption of photons is connected with the tunnelling of electrons through a potential barrier (Fig. 3). The optical transition of the electron can be virtually divided into two parts [28-31]. The first part is a vertical transition on an energy level inside its own localized region (without tunnelling); the second part is a horizontal transition (tunnelling) into a real level in an adjacent localized region. At lower temperatures, the absorption of photons in the vicinity of optical absorption edge could also be realized without the tunnelling process within a single localized region. The probability of such transitions is, however, very small because the lowest energy levels are distinctively discrete as well as because there is a very small number of such levels in a single micro-region. The absorption connected with the tunnelling into adjacent regions is, therefore, more probable.

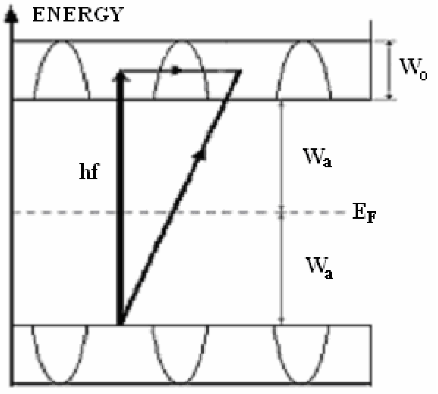

Fig. 3. Optical absorption at lower temperatures.

In the case of a parabolic potential barrier, the dependence of potential energy $W(x)$ of an electron on its position can be expressed as

$$W(x) = -ax^2 + W_o, \qquad (2)$$

where W_0 is the height of the energy barrier measured from the bottom of the conduction band and a is the "narrowness" of the barrier. If $W(x)$ (1) is inserted into the semi-classical approximation of the general formula for the tunnelling probability of a particle, one obtains [28-31]:

$$p(\varepsilon) \approx \exp(-A\Delta W), \qquad (3a)$$

where

$$A = -\frac{\pi}{\hbar}\sqrt{\frac{2m}{a}}, \qquad \Delta W = W_o - \varepsilon \qquad (3b)$$

and m is the mass of the tunnelling electron. The quantity ε is the energy of the tunnelling particle measured with respect to the bottom of the conduction band (Fig. 4).

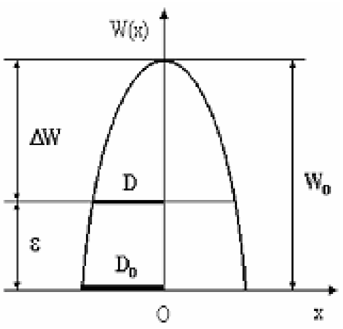

Fig. 4. The parabolic potential barrier.

At low temperatures, the coefficient of the optical absorption α is always assumed to be proportional to the probability of the tunnelling through the potential barrier on the corresponding energy level ε. Thus,

$$\alpha \approx \exp(-A\Delta W)\,. \tag{4}$$

It seems that phonons play no role in the low-temperature absorption [28-31]. However, this is not true. The influence of phonons on the absorption process will be shown in the next sections.

According to Fig. 3.4 for ΔW it holds

$$\Delta W = 2\ W\mathrm{a} + W\mathrm{o} - hf. \tag{5}$$

If this expression is substituted in formula (4) one obtains

$$\ln\alpha\ = Ahf + \text{constante}, \tag{6}$$

which represents an exponential tail of an optical absorption. For as much as a constant in (6) is temperature dependent (as will be shown later) a tail will be parallelly shifted at a change of temperature in low temperature region. Its slope determined by parameter A stays unchanged. This conclusion is in accord with experiments.

1.5 Electroabsoption in the frame of the barrier-cluster model

Inherent mechanism of electroabsorption in a frame of barrier-cluster model was described in the papers [28, 30]. The basic idea rests on the assumption that a strong electric field affects the electron tunneling probabilities across potential barriers. Barrier's profiles are assumed parabolic. An electric field increases the probability of tunneling in the direction of an acting force, while by tunneling in opposite direction the tunneling probability decreases. These two changes induced by the field do not compensate each other. As a result there is little increase of absorption which grows as a quadrate of the field.

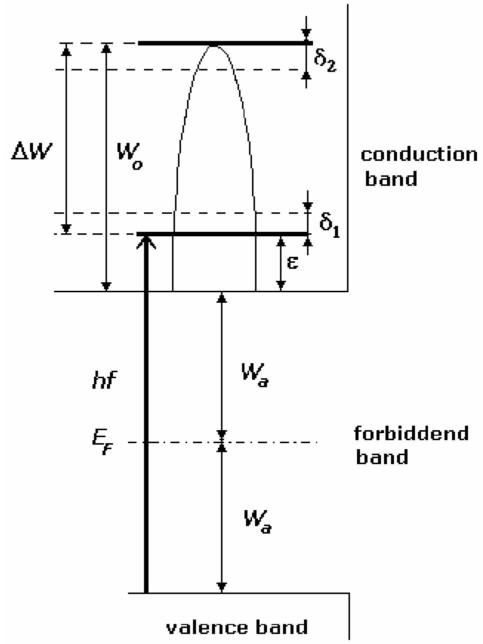

Fig. 5. The influence of the temperature on the process of tunneling of electron trough the potential barrier.

In works [28, 30] formula (7)

$$\frac{\Delta\alpha}{\alpha} = -C_1(hf) + C_2 \tag{7}$$

was derived for electroabsorption in the frame of barrier - cluster model, where Δα/α is the relative change of the absorption coefficient affected by the field.

The values of the parameters C_1 and C_2 have been determined by the relations

$$C_1 = \frac{(AeE)^2}{6a},$$

$$C_2 = \frac{(AeE)^2(W_o + 2W)}{6a}\,. \tag{8}$$

It is also worth mentioning that for the calculation of C_1 and C_2 two parameters only, a and A, were used from the absorption measurement. The physical meaning of parameters a and A is already known (3b).

Therefore, - and it should be stressed - two different parameters C_1 a C_2 were determined at the same time. Moreover, there was neither fitting nor any selection of some auxiliary parameters. Constants C_1, C_2 are both proportional to the square of the field E.

We remark that a comparison of the theory with experiment for the amorphous material As_2Se_3 [1] shows a good agreement of the theory with experiment [28, 30].

2. The influence of temperature on the optical phenomena

2.1 Optical absorption at low temperatures

At low temperatures, the absorption of photons is possible only if the photon energy hf is higher than the width $2W_a$ of the forbidden band. An electron, which absorbs a photon at the zero thermodynamic temperature, acquires the energy hf. At nonzero temperatures, phonons can also supply a certain small quantum of energy to the electron which has absorbed a photon. This supplied quantum of energy depends on the temperature and is statistically determined. Thus, the electron absorbs the energy $hf + \delta_1(T)$, where $\delta_1(T)$ is the average energy supplied by phonons at the temperature T. The quantity $\delta_1(T)$ is assumed to be proportional to the thermodynamic temperature. Thus $\delta_1(T) = K_1T$, where K_1 is a positive constant. This proportionality is in agreement with the fact, that the average energy of absorbed phonons is proportional to k_BT, where k_B is the Boltzmann constant. Hence, the energy tunnelling level is higher than it is at the zero thermodynamic temperature (Fig. 5). At the higher energy level, the probability of the tunnelling is higher. It causes the increase in the absorption.

The optical absorption is also influenced by the temperature dependence of the forbidden band of non-crystalline semiconductors. It is known from experiments that the width of forbidden band decreases with the increase in the temperature. Hence, the quantity $2W_a$ also decreases with the increase in the temperature T. From this follows, that the height of the peak of potential barrier, measured relative to the top of the valence band, is also reduced by some amount δ_2 (Fig. 5). The quantity δ_2 is also assumed to be proportional to the thermodynamic temperature. Thus, $\delta_2 = \delta_2(T) = K_2T$, where K_2 is a positive constant. This assumption is in agreement with the results of experiments in a large range of temperatures. Thus, one can write

$$\Delta W(T) = 2W_a + W_o - hf - \delta_1(T) - \delta_2(T), \qquad (9)$$

$$\Delta W(T) = 2W_a + W_o - hf - CT \ , \qquad (10)$$

where $C = K_1 + K_2$.

Then, it follows from (4) and (10) that

$$\ln\alpha = A(hf + CT) + const. \qquad (11)$$

The expression (11) is the generalization of the relation

$$\ln\alpha = A(hf) + const.$$

used for instance in [28-30]. When the temperature drops from T_1 on T_2, then $\ln\alpha$ changes by the amount

$$\Delta\ln\alpha = AC(T_2 - T_1)\,. \qquad (12)$$

The relation (12) expresses the parallel shift of exponential tails caused by temperature changes. It is in agreement with experimental data [1-7].

From (11) it follows that,

$$C = \frac{1}{A}\frac{d(\ln\alpha)}{dT}\,. \qquad (13)$$

We notice that the constant C according to [31] is equal to the negative value of the thermal coefficient of the optical forbidden band gap width of a chalcogenide glass. An optical gap width decreases linearly with increasing temperature in a broad temperature interval – as it is shown in [45]. Consequently the coefficient C is more or less is constant. This is in agreement with the proposed model.

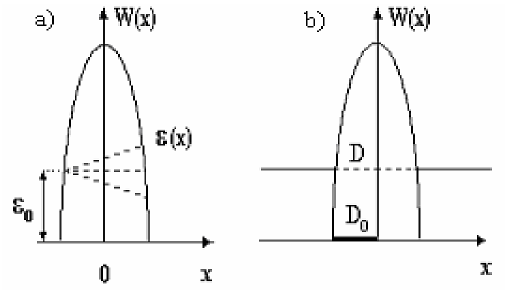

Fig. 6. Tunneling of an electron through the potential barrier in the electric field.

2.2 Electroabsorption

The influence of temperature on tunneling probability

In [28, 30] there was shown that a strong electric field influences the tunneling probability of an electron through a potential barrier and thus, the value of absorption coefficient as well. Just this is the essence of explanation of electroabsorption on the base of a barrier-cluster model.

During tunneling of an electron through a barrier without the presence of external electric field (Fig. 6), the energy of the electron does not change. In external electric field, the electron energy will continuously increase or decrease depending on whether the tunneling process runs in the direction of acting electric force or in the opposite direction. This is true at least in the one-dimensional (1D) case, which is considered now.

If tunneling takes place in homogenous electric field with an intensity E, the electron energy ε will be a function of position [28,30]. In the case depicted in Fig. 6, where the origin of the x-axis is placed in the middle of the barrier in question, it can be written

$$\varepsilon(x) = \varepsilon_o + eED \pm eEx. \qquad (14)$$

The process of tunneling is affected by the temperature. This circumstance enables us to clarify the impact of the temperature upon electroabsorption. The influence of the temperature upon a tunneling process can be accounted by changing the quantity $\varepsilon_o \rightarrow \varepsilon_o + CT$, so that we can write instead of (14) following expression

$$\varepsilon(x) = \varepsilon_o + CT + eED \pm eEx, \qquad (15)$$

where $2D$ is the barrier width on the energy level $\varepsilon_o + CT$ and expresion $\varepsilon_o + CT$ represents initial energy of the tunneling particle at temperature T. The positive upper sign before the last term applies when the particle energy increases in the field. The negative sign applies on decreasing the particle energy (Fig. 5,6).

The term CT in (15) lifts the initial energy level at which begins a tunneling across the barrier.

NOTE: We draw the attention to some simplification which has been done in our precedent consideration. It was said, that growing temperature reduces the energy gap $2W$a of a glass. This is in accordance with knowing data. But we did not take into account thermal changes of the low mobility band of the energy band width W_0. These changes we do not know to evaluate properly. Also, the temperature dependence of W_0 was ignored as well as the temperature influence on inherent potential barriers. In reality the temperature changes certainly contributes to the barrier band as well. As it is well known, the barrier band is much shorter than the forbidden band. This implies that its contribution to the total temperature change is not significant. Besides one can expect the thermal effect of the barrier band will have linear character as well as the forbidden band effect. Consequently, it can be included in a constant C appearing in (15) as its correction. That doesn't change the character of the corresponding relation.

For the probability of tunneling of an electron across the barrier at the temperature T in an electric field we can write on account of the semi-classical formula

$$p(\varepsilon) \approx \exp \left\{ -\frac{2}{h} \int_{x_1}^{x_2} \left\langle 2m\left[-ax^2 + W_0 - \varepsilon_0 - CT - eED - eEx \right]^{1/2} dx \right\rangle \right\}. \qquad (16)$$

[28, 30]. The lower limit of integration, x_1, is obtained from the condition $W(x_1) = \varepsilon_o + CT$, the upper limit, x_2, from condition

$$W(x_2) = \varepsilon_o + CT + eED + eEx_2,$$

where $W(x) = -ax^2 + W_0$. Thus

$$x_1 = \sqrt{\frac{W_0 - \varepsilon_0 - CT}{a}}, \qquad (17a)$$

$$x_2 = \frac{eE \pm \sqrt{(eE)^2 + 4a(W_0 - \varepsilon_0 - CT - eED)}}{2a}. \qquad (17b)$$

After performing the integration (16) in the respective limits, we obtain

$$p(\pm E) \approx \exp \left[-A\left(W_0 - \varepsilon_0 - CT \mp eED + \frac{(eE)^2}{8a} \right) \right]. \qquad (18)$$

where A is given by the formula (3b). Supposing that the last term appearing in parentheses to the exponent is negligible as compared to the previous one, the relation can be re-written as

$$p(\pm E) \approx \exp \left[-A\left(W_0 - \varepsilon_0 + CT \mp eED \right) \right]. \qquad (19)$$

If we put $E = 0$ in the relation (19), we obtain the probability

$$p \approx \exp \left[-A\left(W_0 - \varepsilon_0 - CT \right) \right]. \qquad (20)$$

Therefore, the relation (19) can also be expressed as

$$p(\pm E) \approx p \exp \left[\mp A\ eED \right], \qquad (21)$$

where

$$p \approx \exp \left[-A\Delta W \right], \qquad (22)$$

$$\Delta W = 2W + W_0 - hf - CT. \qquad (23)$$

From (21-23) it follows

$$p(\pm E) \approx p \exp \left[\mp A\ eED \right] = \\ = \text{po} \exp (ACT). \exp \left[\mp AeED \right]. \qquad (24)$$

From this, it is clear that the probability of tunneling of electron in an electric field increases in one direction and decreases in another direction as compared to the original value for $E = 0$.

2.3 Derivation of relations for electroabsorption

According to the barrier model of an amorphous solid, the absorption coefficient in the low temperature range is directly proportional to the probability of tunneling related to the respective energy level. However, two different probability values should be considered during absorption in electric field; the probability of tunneling $p(+E)$ in the direction of acting electric force and the probability $p(-E)$ in the opposite direction. The probability $p(+E)$ is greater whereas the probability $p(-E)$ is smaller than the probability p of tunneling without field. However, these two changes caused by field do not compensate each other. As overall probability $P(E)$ of tunneling an electron in electric field with the intensity E, the sum $p(+E) + p(-E) = P(E)$ will be considered for the one-dimensional (1D) case, where the probabilities $p(+E)$ and $p(-E)$ are given by (21, 22). This is quite similar in the absence of electric field, naturally with $E = 0$. The overall probability of tunneling in absence of field, $P(0)$, is thus $P(0) = p(0) + p(0) = 2p(0) = 2p$ whereby for p, the relation (20) holds true. Let us further suppose that a relative change of absorption under influence of the field is directly proportional to the relative change of the overall probability

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta P}{P} = \frac{p(+E) + p(-E) - 2p}{2p}. \qquad (25)$$

From (24) and (25), we obtain

$$\frac{\Delta\alpha}{\alpha}=\frac{1}{2}\,[\exp\,(AeED)+\exp\,(-AeED)-2)]. \tag{26}$$

Supposing that $AeED$ << 1 (this condition is usually fulfilled as we can demonstrate in numerical examination), the exponential functions appearing on the right-hand side of this relation can be expanded into the Taylor series with the consideration limited to the first three terms of this expansion. In this way, we obtain

$$\frac{\Delta\alpha}{\alpha}=\frac{1}{2}\,(AeED)^2. \tag{27}$$

If $D = x_1$ is substitute in the relation (17a), we obtain

$$\frac{\Delta\alpha}{\alpha} = \frac{1}{2}(AeE)^2\,\frac{W_0-\varepsilon_0-CT}{a}, \tag{28}$$

from which it can be seen that the relative change (increase) of the absorption coefficient is directly proportional to square of intensity of electric field. This is in agreement with the observation. The relation (28) enables us also to explain the dependence of relative absorption $\Delta\alpha/\alpha$ on the energy *hf*.

However, although the photon energy does not appear explicitly in the indicated formula, the quantity ε_o depends on it. Substituting $\varepsilon_o = hf - 2W$ into (28), we obtain

$$\frac{\Delta\alpha}{\alpha}=-\frac{(AeE)^2}{2a}(hf+CT)+\frac{(AeE)^2(W_o+2W)}{2a}. \tag{30}$$

This relation is valid for the one-dimensional model of the sample. The three-dimensionality of a real situation leads to the conclusion that $(1/3).E^2$ shall be used in (30), instead of E^2. So we find

$$\frac{\Delta\alpha}{\alpha}=-\frac{(AeE)^2}{6a}(hf+CT)+\frac{(AeE)^2(W_o+2W)}{6a} \tag{31}$$

and thus, a dependence of the type

$$\frac{\Delta\alpha}{\alpha} = -C_1(hf+CT)+C_2\,. \tag{32}$$

At that, the positive parameters C_1 and C_2 do not depend on the energy of the absorbed photon. Thus, the relative change of absorption decreases in a linear manner with the photon energy. It is a consequence of the negative sign before the positive value of C_1. This conclusion is in agreement with the experimental data [28-31].

2.4 Discusion

It is seen from (32) that an increase of temperature T will cause corresponding decrease of $\Delta\alpha/\alpha$ - quantity and so the graph of the function $\Delta\alpha/\alpha(hf)$ will be shifted towards lower values. Experimental data concerning electroabsorption allow for testing the barrier-cluster model by means of the parameter C. The testing is based upon, that from experimental data of the function $\Delta\alpha/\alpha\,(hf,T)$ belonging to two values of temperature T_1 and T_2 one can determine the difference of photon energies $hf_2 - hf_1$ by using the condition

$$\Delta\alpha/\alpha\,(hf_1,T_1) = \Delta\alpha/\alpha\,(hf_2,T_2) \tag{33}$$

and in such manner the shift of the graph of the function $\Delta\alpha/\alpha\,(hf)$ along the hf – axis. From the formula (32) it follows $\Delta hf = C\Delta T$. By virtue of experimental data on electroabsorption one can determine the value of the parameter C independently from absorption. Then, this result can be compared with the value of the constant C obtained from optical absorption analysis (12, 13). If both values of the C-parameter obtained this way are comparable, this will be an argument for the barrier–cluster model. It is remarkable, that particular evaluation of experimental dependences mentioned above offered relatively well comparable values of the C parameter. This indicates the viability of the barrier-cluster model.

Following the barrier-cluster model for electroabsorption we can understand the experimental results published in [14], especially that the peak of the curve $\Delta\alpha/\alpha\,(hf,T)$, for T_2 = 300 K is shifted if compared with the analogous curve for T_1 = 120 K towards lower photon energy. At the same time the maximum of the curve $\Delta\alpha/\alpha$ (hf) at the temperature 300 K is less as it is at 120 K. This lowering does not follow from equation (13), because that eq. describes a range where the dependence of electroabsoption $\Delta\alpha/\alpha\,(hf,T)$ on temperature is linear. The range in which the electroabsorption $\Delta\alpha/\alpha\,(hf,T)$ exhibits a maximum is bounded to tunneling process across barriers near their bottom. A temperature increase will cause greater energy dispersion of tunneling electrons around the mean value near the bottom of the conduction band. This will show a spreading of the curve close to its maximum. This spreading implies a lowering of its maximum. That effect is clearly confirmed by experiment. Moreover, at higher temperature the energy gap width is also reduced. This constriction contributes to the shift of the maxima location towards the lower energies *hf.*

The open problem is still an electroabsorption at photon energies lower than those corresponding to the peaks of the curves $\Delta\alpha/\alpha$ (hf). In the paper [14] are published the results which indicate that in a given range of energies the value of $\Delta\alpha/\alpha$ sinks with lowering the photon energy. On the other hand, in the article [15] one can find a graph showing that the value of $\Delta\alpha/\alpha$ by lowering the photon energy stays constant. The measurements in a domain of electroabsorption are relatively rare; consequently it is questionable to do any definite conclusions.

3. Conclusions

In the physics of non crystalline materials there are many insoluble problems up to now. Since Kolomiets [46] began first the study of chalcogenide glasses, thousands of papers have been published in the field of glassy semiconductors. The majority of those papers show an experimental character and brought experimental results. The theory in this field is several steps behind the experiment. No model has been suggested yet that would explain satisfactories the wide range of observed phenomena.

The state-of-art (situation) in the theory of non-crystalline solids still stays like that one expressed by H. Overhof in „Fundamental concepts in the physics of amorphous semiconductors“ [47]: „It seems to me, as far as the theory of non-crystalline semiconductors is concerned, that one of the fundamental pillars of the pedestal, on which such a theory should rest, is still unknown to us."

It appears, that outlet from this tricky state can provide an important discovery in the low-dimensional systems, the discovery of the fullerenes based on graphite-like carbon. These discoveries led to the suggestion that other low-dimensional covalent systems, as e.g. chalcogenides could present special configurations similar to fullerenes or nanotubes - clusters. The barrier-cluster model assumes that the glass consists of closed clusters with a potential barrier existing in between.

It seems to us, that the barrier-cluster model, on the ground of which is explained the effect of temperature on the optical absorption and electroabsorption in this paper, gives a new look at a number of important optical and electrical features of chalcogenide glasses. The barrier-cluster model provides a new explanation for the density of states within the forbidden band of a semiconductor and explains why the attempts of identification of gap-states by various optical and other methods fail. The closed-cluster structure can explain the absence of an ESR signal in the case of chalcogenide glasses and also the results of X-ray structure measurements. We assume, that the barrier-cluster model can stimulate the development of new interpretations of physical phenomena in non-crystalline semiconductors, and, specifically, in chalcogenide glasses.

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