THE INFLUENCE OF SAMARIUM IMPURITY ON MECHANISM OF CURRENT PASSING THROUGH Al-$Se_{95}Te_5$<Sm>-Te STRUCTURES

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It is established that current passing through Al-$Se_{95}Te_5$<Sm>-Te structures is carried out by monopolar injection mechanism at participation of traps for holes. The local level parameters (concentration and energy state) controlling the electric charge transfer are defined with the use of existing theories of injection currents. The obtained results are connected with distribution peculiarities of samarium atoms and their chemical activity.

Keywords: chalcogenide glass-like semiconductors, local levels, injection currents, charged centers.
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INTRODUCTION

The chalcogenide glass-like semiconductors (ChGS) are successfully applied in different devices of micro-, nano- and optoelectronics, i.e. in optic storage devices, planar waveguides, fiber amplifiers, optic switches, lasers and etc. [1-6]. Moreover, the given material field of application expands with time. The uniqueness of their electron properties in particular the transparency in visible and nearest IR regions, high photo-sensitivity, optical non-linearity, the ability to change such parameters as refractive index, optical-absorption edge and also potential possibilities of unlimited doping and technological process simplicity promotes to it. However, the application success requires the establishment of electron property controlling methods.

It is known in that ChGS materials the short-range order (SRO) in atom disposition similar to their crystal analogues saves but long-range order (LRO) destroys, i.e. the translation symmetry which is characteristic of crystals. Besides, there are heterogeneities of nano-meter dimension in them, i.e. the medium-range order (MRO) ranges in which there is a definite order in disposition of atoms and structural units. They play the essential role in electron property control similar to elementary cells in crystals. One can modify the dimensions and structures of MRO ranges and thus to influence on electron properties by change of technological process mode, chemical composition and also doping.

The charged centers D^+ and D^- with negative electron correlation energy (U^- are centers) also play the significant role in electron property control of chalcogenide glasses. The fact of paramagnetism absence, i.e. the absence of unpaired electrons, is the confirmation of their existence [7-8]. One can change the given center concentrations and thus directly change their electron properties by different methods. The present paper is devoted to the investigation of charged center role in transfer processes of electric charge through Te- $Se_{95}Te_5$ – Al structure and samarium impurity influence on it at accompaniment of injection from contacts. It is supposed that given centers create the local states in $Se_{95}Te_5$ forbidden band, the completing and ionization of which with field control the conduction mechanism in strong electric fields. The given composition choice in the capacity of investigation object is caused by the fact that the substitution of selenium atom parts by tellurium ones promotes to partial destroy of Se_8 rings, shortening of chain molecule length and dangling bound concentration increase. The use of samarium for doping connects with the fact that samarium as chemically active element revealing two- and three-valence and also taking part as positive ions, can form new structural elements with selenium and tellurium atoms and promote to change of relative concentration of charged centers. Thus, the use in capacity of addition of tellurium and samarium doping element should lead to change of structure and charged defect concentration of amorphous selenium that allows us to influence on its electron properties. This helps us to find the ways of successful practical use of given ChGS material, i.e. to broaden the region of its application.

THE EXPERIMENT TECHNIQUE AND SAMPLE PREPARATION

ChGS synthesis of $Se_{95}Te_5$ composition with samarium impurity is carried out by melting of corresponding qualities of essential purity chemical elements in vacuum quartz ampoules up to 10^{-4} millimeter of mercury at temperature 900 ^{0}C in rotating furnace with aftercooling in mode of switched furnace. The impurity is introduced in synthesis process, its concentration lies in limits 0,05÷1at %. The volt-ampere characteristics (VAC) are measured in stationary mode by standard technique. The samples are presented themselves “sandwich” with aluminum and tellurium electrodes and are prepared by the method of thermal evaporation in vacuum ~ 10^{-4} millimeter of mercury. The film thickness is measured by interferometric method and is varied in range 1-10μm. VAC of Al-$Se_{95}Te_5$<Sm>-Te structure is investigated at constant current at positive potential applied to Te.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

VAC of investigated structure at room temperature is shown on figure. As it is seen in double logarithmic scale VAC consists of several clearly marked straight-line portions corresponding to current power dependences (*I*) on applied voltage (V). In many samples $I \sim V^n$ ($n \leq 1$) dependence is observed at small voltages. Further $I \sim V^n$ dependence where n takes the different values in VAC different portions that confirms the charge carrier transfer (holes) in given structure is carried out by monopolar injection current mechanism limited by volume charges (CLVC) at participation of charge capture traps [10]. As it is seen from graphs the samarium impurity has complex influence on current passing mechanism that one can explain by changes taking part in energy spectrum of localized states inside the forbidden band.

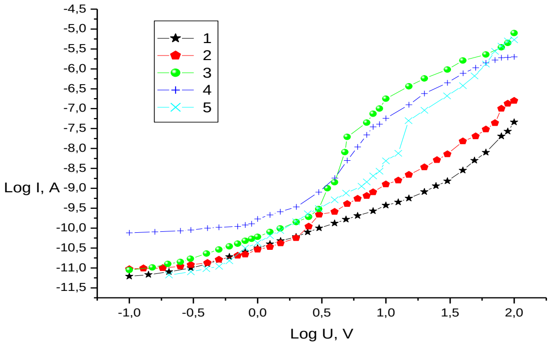

Fig. 1. The volt-ampere characteristics of $Se_{95}Te_5$ composition with samarium imprurity: 1is $Se_{95}Te_5$; 2is $Se_{95}Te_5Sm_{0,05}$; 3is $Se_{95}Te_5Sm_{0,1}$; 4is $Se_{95}Te_5Sm_{0,5}$; 5is $Se_{95}Te_5Sm_1$ taken at room temperature on films of thickness 3µm.

VAC of Al-$Se_{95}Te_5$-Te structure in initial portion satisfy to ohmic law which transit to the region corresponding to power law with voltage increase, i.e. $I{\sim}V^n$, where n exceeds 2. Such VAC behavior confirms that the electric charge transfer in given material is controlled by capture trap centers for holes situated higher Fermi level. Shallow levels (situated below Fermi level) either are absent, or the concentration of deep states so high one that their completing in given voltages isn't finished (big voltages lead to layer breakdowns). According to CLVC theory [10] the electric charge transfer is controlled by shallow levels after the fact that deep traps are fully completed by charge carriers. If one take into consideration that carrier transport [7-12] in ChGS materials is controlled by charged centers (D^+ и D^-) with high concentrations (for $Se_{95}Te_5$~ 10^{18}cm^{-3} [13]) then the prognosis confirm. In layers containing the small concentrations of samarium impurities (up to 0,1%), the voltage, at which the power dependence begins, shifts to the small voltage value and the quadratic dependence is observed in following region, i.e. $I{\sim}V^2$ which is substituted by power law with voltage increase again. This obviously is connected with decrease of deep trap concentration and formation of new shallow traps. VAC of layers with samarium impurity big concentrations (concentration ≥ 0,5at%) beginning from ohmic law transforms into quadratic one and region of trap total filing which is substituted by quadratic law with voltage increase. The power law of current strength dependence on applied voltage is observed in last portion. According to CLVC theory [10] such VAC behavior confirms the existence of two groups of shallow traps controlling the electric charge transfer.

The observable VAC changes of $Se_{95}Te_5$ layers with doping level change can be explained by peculiarities of samarium impurity atom distribution, their revealing in the form of positive ions in amorphous matrix and also by involvement of charged defect model. It is supposed that local electric fields existing round charged defects D^+ and D^- and structural distortions near them and also samarium big ion radius promote to the fact that D^- centers play role of ones effectively capturing samarium positive ions. Thus, samarium ions in small concentrations mainly accumulate round D^- centers in amorphous matrix that promotes to electric field screening of these centers. This leads to the fact that concentration of D^- defects, actively captured the holes decrease and that's why the region of trap limiting filling begins at small voltages and the shallow traps appear at not high voltages. It is supposed that in ChGS investigated system there are two groups of local states connected with selenium and tellurium atoms (as the shallow traps are observed in pure amorphous selenium). The new local states also situated below Fermi level form at big concentrations of samarium impurity.

Using the known theory of injection currents [10] in ChGS system of $Se_{95}Te_5$ doped by samarium one can define some parameters characterizing the electric charge transfer and also parameters of hole capture traps given in table 1.

From VAC ohmic portions the film resistivity values are calculated and using it, the concentrations of equilibrium free holes (table) are estimated according to formula $\rho = (ep_0\mu)^{-1}$ where e is elementary charge and μ is charge carrier drift mobility (for holes μ = 10^{-3} cm^2/(V·sec) [13]). Using these data Fermi level position in forbidden band ($F_o - E_v$), где N_v is effective state density in valence band (N_v =10^{20} см$^{-3}$ [7]), κT is heat energy, is defined by the following formula:

$$p_0 = N_v exp\left(-\frac{F_0 - E_v}{kT}\right) \tag{1}$$

Table 1

	$Se_{95}Te_5$	$Se_{95}Te_5Sm_{0.05}$	$Se_{95}Te_5Sm_{0.1}$	$Se_{95}Te_5Sm_{0.5}$	$Se_{95}Te_5Sm_1$
ρ	$2.67*10^{12}$	$7.1*10^{12}$	$1.98*10^{12}$	$1.3*10^{12}$	$9.1*10^{12}$
P_0	$4.68*10^9$	$1.7*10^9$	$6.3*10^9$	$9.6*10^9$	$1.38*10^9$
F_0-E_v	0.62 eV	0.64 eV	0.61 eV	0.6 eV	0.65 eV
P_{t02}	$9.2*10^{14}$	$2.1*10^{14}$	$2.5*10^{15}$	$1.8*10^{14}$	$6.1*10^{14}$
E_{t2}-F_0	0.16 eV	0.2 eV	0.14 eV	-	-
P_1	-	$1.8*10^{15}$	$6*10^{15}$	-	$2.15*10^{15}$
E_{t1}-E_v	-	0.55 eV	0.51 eV	-	0.51 eV
E_{t2}-E_v	0.78 eV	0.75 eV	0.75 eV	0.58 eV	0.57 eV

The ohmic portion precedes to the one corresponding to fully completed trap for $Se_{95}Te_5$ samples without impurity and with small impurity content and that's why (p_{t02}) concentration primarily not taken by trap holes with E_{t2} energy is calculated from the following equation:

$$V_{FCT} = \frac{ep_{t02}L^2}{\varepsilon} \tag{2}$$

and values are given in table. Here V_{FCT} is voltage at which the fully completed trap portion E_{t2} begins. As it is seen from table $p_{t02} \rangle\rangle p_0$. As it is above mentioned the deep levels are connected with D^- - centers in investigated materials. Taking the concentrations of (N_{t2}) given centers by 10^{18} cm^{-3} order [13] the energy position of level E_{t2} is calculated by the following formula:

$$p_{t02} = \frac{N_{t2}}{1+g_A\exp(\frac{E_{t2}-F_0}{kT})} \approx \frac{N_{t2}}{g_A}\exp(\frac{F_0-E_{t2}}{kT}) \tag{3}$$

It is considered that g_A= 2.

The quadratic dependence of current strength on voltage is observed in VAC portion following the region of fully completed deep traps, i.e. VAC satisfies to law:

$$I = \frac{\theta\varepsilon\mu V^2}{L^3} \tag{4}$$

where θ characterizes the free carrier part of all injected ones.

$$\theta = \frac{N_c}{gN_t}\exp\frac{E_t-E_c}{kT} \tag{5}$$

According to [7] only one discrete level influences on current. If there are several groups of shallow attachment levels that is expected in ChGS material containing the REE impurity atoms, then the group with θ least value more strongly restricts the current and parameter θ, connected especially with this group, includes into (4).

θ values are estimated by the following formula:

$$V_x \approx \frac{ep_{0}L^2}{\theta L^2} \tag{6}$$

where V_x is voltage at which I~V^2 dependence begins. Using the voltage at which the current strong increase is observed, the concentration of traps (p) are not occupied by holes is calculated by formula (2).

According to (10) in given case p = N_{t1} , where N_{t1} is total concentration of shallow traps. Knowing N_{t1} and θ, the accumulation depths of the given traps the results of which are shown in table, are calculated by formula (5).

The quadratic dependence of current strength on voltage precedes the VAC portion corresponding to current strength strong increase for $Se_{95}Te_5$ samples with samarium big concentrations (0,5; 1 at%), that confirms the fact that traps controlling the charge transport are shallow ones, i.e. they posit below Fermi level.

Using (2), (5) and (6) formulae, the concentration and accumulation depth of traps for these samples are defined and obtained results are given in table.

CONCLUSION

It is established that current passing through Al-$Se_{95}Te_5$<Sm>-Te structures is carried out by monopolar injection mechanism at participation of traps for holes. It is shown that doping by samarium strongly influences on current passing mechanism in investigated structure that is explained by change taking place in energy spectrum of local states. In pure $Se_{95}Te_5$ electric charge transfer is controlled by homoenergetic levels posited higher Fermi level. In $Se_{95}Te_5$ containing the small concentrations of samarium impurity (0,1 at %) the current passing mechanism is controlled by two groups of local levels posited on both sides of Fermi level.

In $Se_{95}Te_5$ doped by samarium high concentrations (0,5; 1 at %) the two groups of local levels posied below Fermi level (both levels are shallow ones) take part in controlling of current passing. It is supposed that local levels are connected with dangling bonds: deep levels are connected with tellurium atoms (D^- is center), shallow ones are connected with selenium atoms. The local level parameters (concentration and energy positions) are defined by use of existing theories of injection currents. The obtained results are connected with distribution peculiarities of samarium atoms and their chemical activity.

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