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TRANSFER OF ELECTRIC CHARGE THROUGH $\text{Al-Se}_{95}\text{Te}_5\langle\text{Sm}\rangle\text{-Te}$ STRUCTURE

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ABSTRACT

It is established that current passing through $\text{Al-Se}_{95}\text{Te}_5\langle\text{Sm}\rangle\text{-Te}$ structures is carried out by monopolar injection mechanism at participation of traps for holes. It is shown that the doping by samarium strongly influences on the current flow mechanism in the investigated structure due to changes in the energy spectrum of the local states. The local level parameters (concentration and energy state) controlling the electric charge transfer are defined with the use of existing theories of injection currents.

Keywords

Chalcogenide glass-like semiconductors; local levels; injection currents; charged centers.



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1. INTRODUCTION

Nowadays the amorphous and glassy selenium as typical representative CGS materials is intensively investigated. However, the obtained results don't agree with each other that prevent its many-functional usage in practical aims. This is, first of all, connected with its various structural elements, i.e. with the existence of ring and chain molecules of different dimension and also big concentration defects with negative correlation energy (U^- -centers) appearing as a result of the presence of dangling bonds. The additions of iso-electronic (sulfur and tellurium) and branching (arsenic) elements [1] and impurities revealing in the ion forms (halogens and rare-earth elements) [2-3] lead to changes in local structure (dimensions and macromolecule numbers) and U^- - concentrations of centers. All above mentioned allow us to change directly the electron properties of given semiconductor and increase its crystallization stability that it is necessary for enlargement of range of application. 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 competing 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 rings, shortening of chain molecules 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.

2. 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 $900^{\circ}C$ in rotating furnace with aftercooling in mode of switched furnace. The impurity is introduced in synthesis process, its concentration lies in limits $0.05 \div 1$ at %. The volt -ampere characteristics (VAC) are measured in stationary mode by standard technique. The sample are presented themselves "sandwich" with aluminum and tellurium electrodes and are prepared by the method of thermal evaporation in vacuum $\sim 10^{-4}$ millimeter of mercury. The film thickness is measured by interferometric method and is varied in range 1-10 μm . VAC of Al- $Se_{95}Te_5$ <Sm>-Te structure is investigated at constant current at positive potential applied to Te.

3. EXPERIMENTAL RESULTS AND THEIR DISCUSSION

VAC of investigation 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 change 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 [4]. 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.

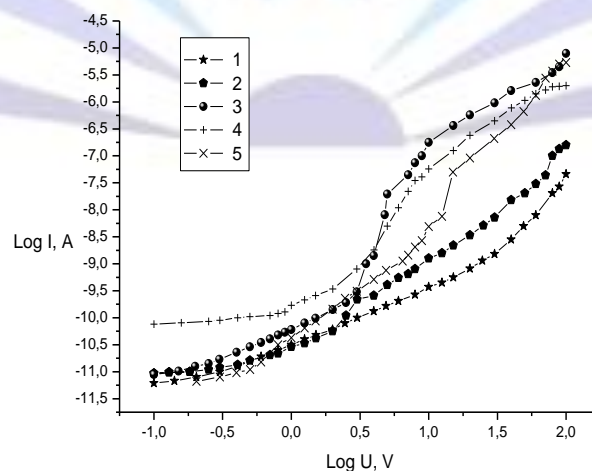


Fig. 1 The volt-ampere characteristics of $Se_{95}Te_5$ composition with samarium impurity: 1 is $Se_{95}Te_5$; 2 is $Se_{95}Te_5Sm_{0.05}$; 3 is $Se_{95}Te_5Sm_{0.1}$; 4 is $Se_{95}Te_5Sm_{0.5}$; 5 is $Se_{95}Te_5Sm_1$ taken at room temperature on films of thickness 3 μm .



VAC of Al-Se₉₅Te₅-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 CLCV theory [4] the electric charge transfer is controlled by shallow levels after the fact that deep traps are fully completed by charge carries. If one take into consideration that carrier transport [1-6] in ChGS materials is controlled by charged centers (D^+ and D^-) with high concentrations (for Se₉₅Te₅ $\sim 10^{18}$ cm⁻³ [7]) 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 ≥ 0.5 at%) 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 [4] such VAC behavior confirms the existence of two groups of shallow traps controlling the electric charge transfer.

The observable VAC changes of Se₉₅Te₅ 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 know theory of injection currents [4] in CHGS system of Se₉₅Te₅ doped by samarium one can define some parameters characterizing the electric charge transfer and also parameters of hole capture traps given in table 1.

Table 1. ρ – resistivity of the films, p_0 – concentration of the equilibrium free holes, F_0-E_v – energy state of Fermi level, p_{t02} – concentration of deep traps unoccupied holes, $E_{t2}-E_v$ – energy state of deep traps, p_1 – concentration of shallow traps unoccupied holes, $E_{t1}-E_v$ – energy state of shallow traps, $E_{t2}-F_0$ – energy separation between Fermi level and deep traps.

	Se ₉₅ Te ₅	Se ₉₅ Te ₅ Sm _{0.05}	Se ₉₅ Te ₅ Sm _{0.1}	Se ₉₅ Te ₅ Sm _{0.5}	Se ₉₅ Te ₅ Sm ₁
ρ	$2.67 \cdot 10^{12}$	$7.1 \cdot 10^{12}$	$1.98 \cdot 10^{12}$	$1.3 \cdot 10^{12}$	$9.1 \cdot 10^{12}$
p_0	$4.68 \cdot 10^9$	$1.7 \cdot 10^9$	$6.3 \cdot 10^9$	$9.6 \cdot 10^9$	$1.38 \cdot 10^9$
F_0-E_v	0.62 eV	0.64 eV	0.61 eV	0.6 eV	0.65 eV
p_{t02}	$9.2 \cdot 10^{14}$	$2.1 \cdot 10^{14}$	$2.5 \cdot 10^{15}$	$1.8 \cdot 10^{14}$	$6.1 \cdot 10^{14}$
$E_{t2}-F_0$	0.16 eV	0.2 eV	0.14 eV	-	-
p_1	-	$1.8 \cdot 10^{15}$	$6 \cdot 10^{15}$	-	$2.15 \cdot 10^{15}$
$E_{t1}-E_v$	-	0.55 eV	0.51 eV	-	0.51 eV
$E_{t2}-E_v$	0.78 eV	0.84 eV	0.75 eV	0.58 eV	0.57 eV

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 $\mu = 10^{-3}$ cm²/ (V·sec) [7]). Using these data Fermi level position in forbidden band ($F_0 - E_v$), where N_v is effective state density in valence band ($N_v = 10^{20}$ cm⁻³) [7]), kT is heat energy, is defined by the following formula:

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

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



$$V_{\text{FCT}} = \frac{ep_{t02}L^2}{\varepsilon} \quad (2)$$

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 $p_{t02} \gg p_0$. 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 [7] the energy position of level E_{t2} is calculated by the following formula:

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

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:

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

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

$$\theta = \frac{N_c}{gN_t} \exp\left(\frac{E_t - E_c}{kT}\right) \quad (5)$$

According to [5] 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:

$$V_x \approx \frac{\varepsilon p_0 L^2}{\theta L^2} \quad (6)$$

where V_x is voltage at which $I \sim V^2$ 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 [4] 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 $\text{Se}_{95}\text{Te}_5$ samples with samarium big concentrations (0.5; 1at%), 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) formula, the concentration and accumulation depth of traps for these samples are defined and obtained results are given in table.

4. CONCLUSION

It is established that current passing through $\text{Al-}\text{Se}_{95}\text{Te}_5\langle\text{Sm}\rangle\text{-Te}$ 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 $\text{Se}_{95}\text{Te}_5$ electric charge transfer is controlled by homoenergetic levels posited higher Fermi level. In $\text{Se}_{95}\text{Te}_5$ 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 $\text{Se}_{95}\text{Te}_5$ doped by samarium high concentrations (0.5; 1at%) 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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