# OPTICAL FIBERS OF TELECOMMUNICATION DEVICES ON THE BASE OF Se - As SYSTEM, DOPED BY ATOMS OF SAMARIUM

**A.I.Isayev, S.I.Mekhtiyeva, N.Z.Jalilov, R.I.Alekperov, V.Z.Zeynalov**

*Institute of Physics of the Azerbaijan NAS*
*AZ 1143, Baku, G.Javid pr., 33*

## ABSTRACT

It is established at investigation of optical properties of the $Se_{95}As_5$ CVS structure containing impurity of samarium, that there is a correlation between dependences of optical absorption factor ($\alpha$), its photoinduced change ($\Delta\alpha$), effective concentration of the charged defects ($N_t$) and the characteristic energy ($E_0$), corresponding to Urbach absorption on the concentration of entered atoms of rare impurity elements (Sm). It is shown, that absorption of light in the spectrum region corresponding to Urbach rules and in the weak absorption region, i.e. in the «tail» area is controlled by the charged defects ($U^-$ - centers). It is established, that changing the impurity atoms content it is possible to change concentration of intrinsic charged defects that allows controlling the optical properties of CVS material.

**Keywords:** optical, photoinduced, absorption, concentration, defects.

## I. INTRODUCTION

The present work is devoted to investigation of optical properties of the $Se_{95}As_5$ chalcogenide vitreous semiconductor (CVS) system containing rare earth impurity of Sm. Choice of the $Se_{95}As_5$ CVS system as object of investigation is based on those reasons, that the specified material, both on structure, and on electronic properties is more stable and wide-gap semiconductor [1-7], and the choice of rare elements resulting from that the CVS, containing ions of rare elements are applied in manufacture of the optical paths switches of the near IR region. It is supposed, that impurity of samarium can be shown as positively charged centers and will influence on the concentration of intrinsic charged defects ($U^-$ - centers). Changing the concentration of $U^-$ - centers, it is possible to operate electric, optical and photoelectric properties of the CVS that is very important for practical application.

## II. EXPERIMENTAL TECHNIQUE AND MANUFACTURING OF SAMPLES

Synthesis of CVS of the $Se_{95}As_5$ composition with samarium impurity was carried out by alloying of corresponding amounts of the chemical elements special cleanliness in the vacuum quartz ampoules at temperatures above 900°C in the rotating furnace, with the subsequent cooling at switching off furnace. The impurity was entered during synthesis, which concentration was about 0,001÷ 1at %.

The factor of optical absorption is investigated by the method of two-beam spectroscopy in the energy interval of 1 ÷ 2,8 eV.

Samples for measurements were the layers with thickness of 0,5 μm ÷ 2 mm. Thin films are prepared onto the glass substrates by the method of thermal evaporation in vacuum of $10^{-6}$ mm.mr.cl.

## III. RESULTS AND DISCUSSION

The spectra of optical absorption factor of the $Se_{95}As_5$ CVS with the various contents of samarium impurity are presented in fig.1a.

As seen from figure, the spectral distribution curves of the absorption factor for all samples shows the features inherent in CVS materials, i.e. dependence of $\alpha(h\upsilon)$ is due to Urbach rule in the photon energy region of 1.6 ÷ 2 eV, at energies higher than 2 eV power dependence, and at energies lower than 1,6 eV the "tail" absorption were observed. Accepting, that the absorption of light in the energy region higher than 2 eV corresponds to electron transitions on the prevailing states («zone-zone» transitions), and also parabolic distribution of state density at valence zone and at conductivity zone by application of formula of Tauc [8]

$$\alpha(h\upsilon) = A(E_g - h\upsilon)^p / (h\upsilon)^m n(h\upsilon) \qquad (1)$$

the dependence of $\alpha(h\upsilon)$ on the light energy is constructed, which the results are presented in fig. 1b, where p = 2, m = 1 and $n(h\upsilon)$- is a refraction parameter, A - is constant.

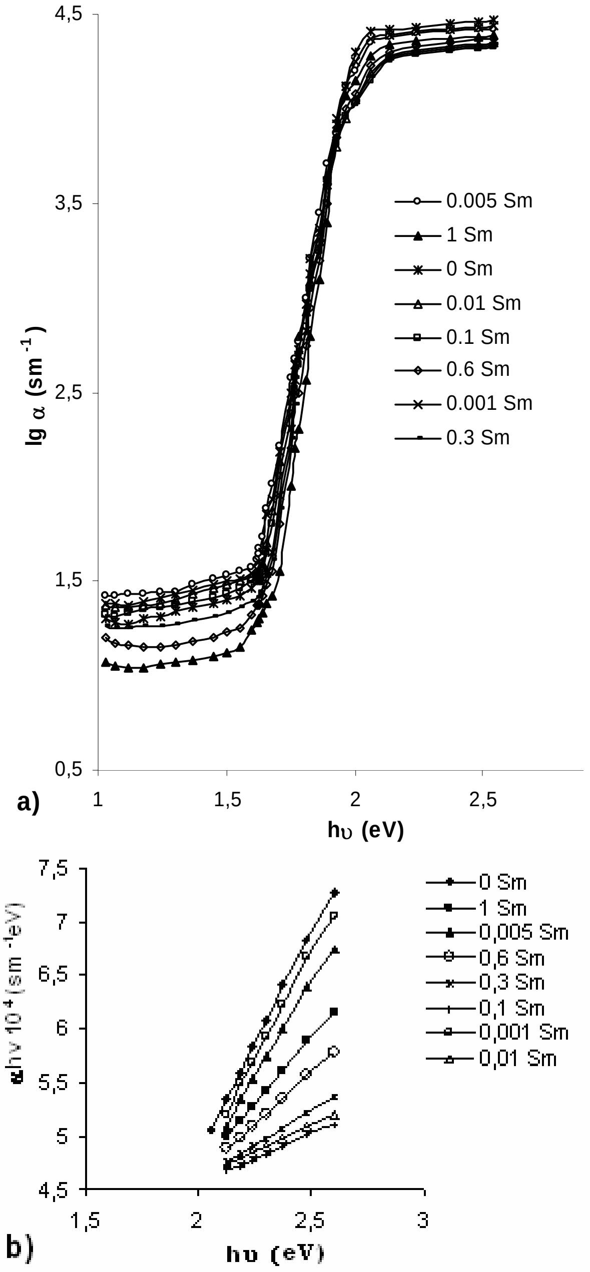


Fig. 1 The spectra of optical absorption factor (a) and dependences of αhν on the energy of falling radiation (b) of $Se_{95}As_5$ system doped by samarium (0.001-1 at %).

The width of band gap is about $E_g \approx 1,95$ eV for all samples and does not depend on concentration of the samarium impurity.

The absorption factor submits to Urbach rule in the intermediate region of spectrum, i.e. in the photon energy region of 1.6 ÷ 2 eV,

$$\alpha = \alpha_0 \exp [- ( E_g - h\upsilon)]/E_0 \quad (2)$$

Where $E_0$ - is the characteristic energy, which characterizes steepness (smear degree) of the edges, and carries information on the root-mean-square rejection of internuclear distances in vitreous matrix [9]. The values of characteristic energy ($E_0$) for all samples are determined from exponential region, which results are presented in fig. 2a as dependence on the concentration of Sm impurity.

In [10] by utilization the model of casual field created by charged atoms chaotically distributed in space for characteristic energy the formula

$$E_0 = 2,2\ W_B\ (N_t a_B^3)^{2/5} \quad (3)$$

is fined. Where $W_B = e^2/2\varepsilon a_B$, $a_B$- is the Bohr radius in substances, $\varepsilon$ - is the dielectric permeability, $N_t$- is the effective concentration of the charged defects. Accepting dielectric permeability values equal to [11], the concentration of the charged defects ($N_t$) are calculated by the formula of (3) and the obtained results are presented in fig. 2a. As seen from fig. 2a, b, with increasing the concentration of entered Sm impurity atoms of up to 0,005 at %, the value of characteristic energy and concentration of the charged defects increases and further increase of impurity atoms concentration results to decreasing as $E_0$ and $N_t$.

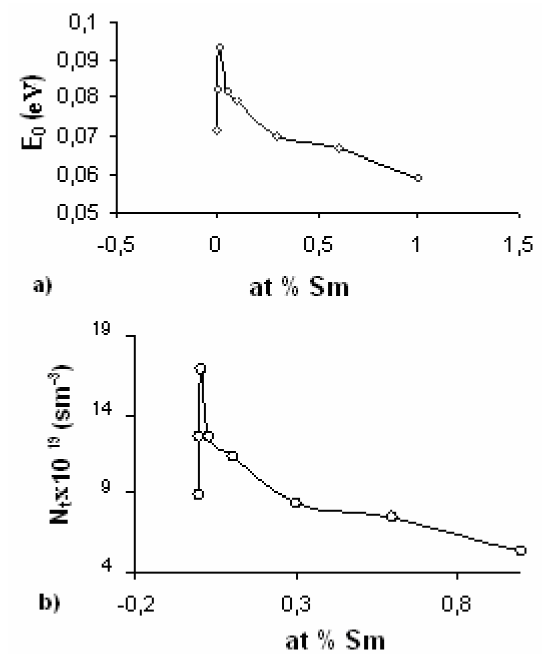


Fig. 2 Dependence of characteristic energy (a) and concentration of the located states (b) in $Se_{95}As_5$ system on the composition of samarium impurity.

Fig. 3a, b, c shows the dependences of optical absorption factors of the $Se_{95}As_5$ CVS on the concentration of the entered samarium atoms in the power dependence region (fig. 3a), in the Urbach region (fig. 3b) and in the "tail" region, i.e. when energy of a photon is lower, than urbach absorption (fig. 3c). It is clearly seen, that dependence of optical absorption factor on the concentration of Sm atoms both in urbach, and in a "tail" region almost repeats the dependence for $E_0$ and $N_t$.

However, in the urbach region the impurity of Sm strongly influence on the value of optical absorption factor. As seen from fig. 3a influence of Sm impurity on the value of optical absorption factor in the region of power dependence, i.e. at photon energies exceeding 2 eV differs from above mentioned regions; the factor of optical absorption decreases up to 0,1 at % of the samarium contents, i.e. there is "blooming" of samples, and the further increase of concentration of the Sm atoms results to gradual increase of the factor, i.e. "fogging" of the sample. The above-mentioned facts of influence of rare impurity elements on the optical properties of $Se_{95}As_5$ testify to complex character of influence of the specified impurity on their structure and electron properties.

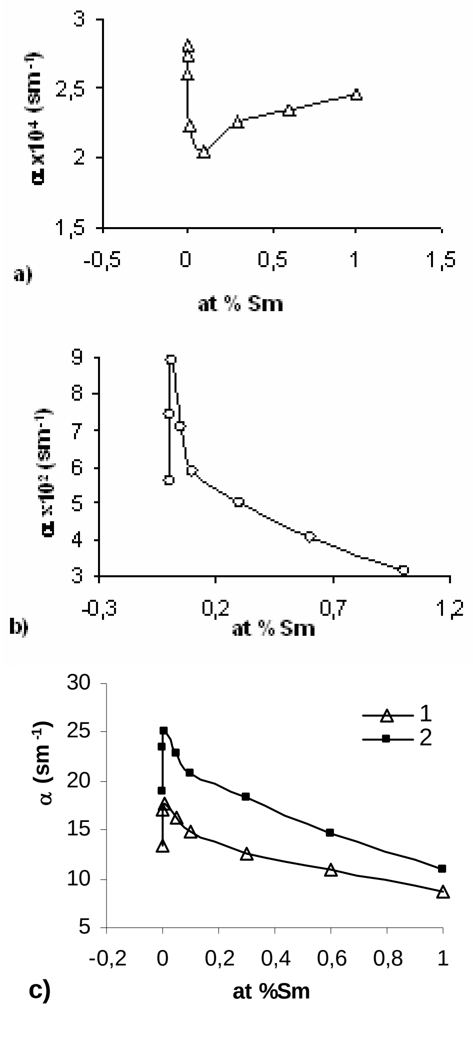


Fig. 3 Dependence of optical absorption factor on the composition of samarium impurity in the power dependence region (a), in the region of Urbach absorption (b), in the energy region lower than Urbach absorption (c).1-at illumination, 2 - dark

Fig. 4a, b shows the spectral distribution of optical absorption factor of the $Se_{95}As_5$ CVS structure containing 0,01 at. % of Sm without illumination and under the strongly absorbed light which photon energy of ≈2 eV (fig. 4a) and dependence of photoinduced change of the optical absorption factor on the concentration of entered Sm atoms (fig. 4b). As seen, additional illumination influences on the value of optical absorption factor only in the "tail" region, i.e. in the given region takes place the "photoblooming".

The "blooming" also has been observed in $As_2Se_3$ CVS films by the authors of work [12], modified by complex compounds of rare elements and the obtained results are explained by introduction of "lightweight" elements to film volume, before the introduction of oxygen to compounds of rare elements, i.e. formation of new chemical compounds of AsO, SeO. Such explanation is not comprehensible to our investigation as technological process and preparation regimes of samples exclude the introduction of oxygen to the film structure. Independence of band gap width of the $Se_{95}As_5$ CVS compositions on the concentration of entered samarium atoms testifies that specified impurity atoms influence, basically, on the electronic states located inside the band gap and in the edges of the conduction zone. The set of the observed experimental facts allows stating the number of reasons about the influence of rare atoms of Sm on the optical properties of $Se_{95}As_5$.

The below-mentioned experimental facts testify to connection of optical absorption factor with the charged defects:

- Dependence of optical absorption factor of the $Se_{95}As_5$ CVS on the concentration of the entered samarium a toms, in urbach (fig. 3b) and in "tail" region (fig. 3c), i.e. in the region of weak absorption;
- Observation of "photoblooming" in the "tail" region, i.e. decrease of the optical absorption factor under action of stimulating light from the intrinsic absorption region (fig. 4a) and dependence of photoinduced change of the optical absorption factor on the concentration of entered atoms of Sm (fig. 4b);
- Observation of correlation between the dependences of optical absorption factor, values of the characteristic energy ($E_0$) corresponding to urbach absorption, concentration of the charged defects ($N_t$) on the concentration of the entered atoms of samarium (fig. 2, 3)

The origin of exponential region (urbach absorption) in the absorption spectrum while unequivocally does not explain. However, by present time it is universally recognized that urbach absorption is directly connected to the structural disorder [19]. Analyzing the experimental facts concerning optical properties, authors of work [22] has come to conclusion, that characteristic energy urbach absorption $E_0$ is the parameter determining the degree of the disorder and dependent on the such factors, as dominating type of chemical connection, coordination number of vitrificator and the size of atoms in sublattice of the modifier. The parameter of disorder ($E_0$) in chalcogenide glasses is lower than in others vitreous materials and that, apparently, are due to the greater covalence connections in them.

According to [18], the origin of urbach absorption is due to fluctuation of potential of the electrostatic type.

Detailed calculations of the absorption factor and its dependence on the external electric field were carried out in [19] by the regime of casual smooth fields of electrostatic type and in work [20] transitions with participation of phonons are taken into account. According to [20] tail in absorption is defined by the Frank-Kiddush's effect in the internal casual electrostatic field which origin can be connected to spatial fluctuations of concentration of the charged defects or impurity [21].

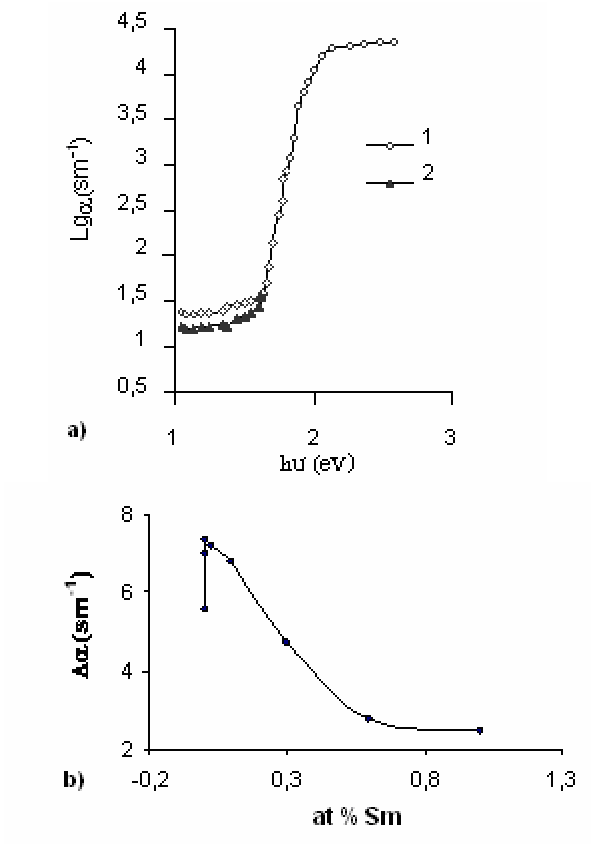


Fig. 4 a) Dependence of optical absorption factor on the radiation energy of the $Se_{95}As_5$ system with impurity of 0.01at % (1), the same dependence at illumination (2) b) Dependence of photoinduced change of the optical absorption factor for $Se_{95}As_5$ system on the amount of samarium impurity.

In work [23] two groups of materials were allocated by structural features, and on flexibility of structure. One group includes those materials at which structural matrixes contain bridging connections and are more mobile owing to what formation of the disorder regions occurs without infringement of continuity of the grid. In the second group - the materials possessing less labile and more rigid structure. Introduction in such system of various modifiers results in formation of the ordered regions of the average order, i.e. microarea with high coordination number. Thus between various regions there are potential barriers which heights is determined by the charged centers. If to accept, that the entered samarium atoms are as $Sm^{+3}$ ions and they basically in small amounts, collect in regions with the increased coordination number, i.e. the degree of structural disorder and heterogeneity on distribution of the charged centers, and also power height of potential barriers that should lead to to increase in such parameters, as absorption factor, concentration of the charged centers and characteristic energy that was really observed at small concentration - up to 0,005 at % of Sm (fig. 2,3). At the height concentration of $Sm^{3+}$ impurity ions being allocated by all matrixes and due to chemical activity drawing to them the ends of selenic circuits promote the structural reorganization resulting in formation of disorder grid and simultaneously form connections between the various microareas. On the other hand, according to model of the charged defects, presence of $Sm^{3+}$ ions should lead to change of concentration of the intrinsic charged defects: to decrease of $D^+$ and to increase of $D^-$. Joint influence of the specified factors results in reduction of characteristic energy of the urbach absorption and concentration of the charged defects controlling urbach absorption owing to what there is "blooming" of the material that is observed at the height concentration of Sm impurity (fig. 2, 4). The observation of "photoblooming" only in the weak absorption region, and also appearance of maximum in dependence of photoinduced change of the optical absorption factor on the concentration of entered atoms Sm at 0,005 at % (fig. 4b), i.e. at concentration where the optical absorption factor and concentration of the charged defects possess the maximal value once again testify that absorption of light in the specified region of the spectrum is due to the transitions between zones and states of $D^+$ , $D^-$ which concentration at photoexcitation goes down in comparison with the equilibrium.

## IV. CONCLUSIONS

It is established, as a result of investigation of optical properties of the $Se_{95}As_5$ CVS structure containing impurity of samarium, that there is correlation between dependences of optical absorption factor (α), its photoinduced change (Δα), effective concentration of the charged defects ($N_t$) and the characteristic energy ($E_0$) corresponding to urbach absorption on the concentration of entered impurity atoms of the rare elements (Sm). It is shown that absorption of light in the region of spectrum, which is due to the Urbach rules, and in the weak absorption region, i.e. in "tail" region is controlled by the charged defects ($U^-$ - centers). It is established; that change of the impurity atoms content it is possible to change concentration of intrinsic charged defects that allows controlling the optical properties of CVS material.

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