

Novel materials and structures for solar energy conversion

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1. Introduction

Although photovoltaic conversion of sunlight into electricity is a well-known concept, only recently the intense efforts have been made to reduce the conversion cost [1]. This has been done by realizing the amorphous $p-n$ junctions using the a -Si based (polymer) materials (a -Si:H:D:C:N:F:...) and planar large square area technology [2,3]. However, full commercial success can be achieved when the barrier of solar conversion energy cost about 1 USD/W will be reached. This requires novel perspective materials for photovoltaic structures (PhVS) to be developed and new physical ideas for solar energy conversion to be elaborated. To solve this problem a remarkable progress in the theory of the disordered matter of the importance comparable with that of the "Blochs Theorem" for crystalline one is to be achieved. Amorphous, especially polymer, semiconductors are the link between the crystalline and the liquid matter, and new ideas and conceptions are urgent in constructing such theory.

The motivation of this research is the existence of a promising class of amorphous materials, speaking more strictly, the non-organic polymers and new technologies appropriate for solar energy conversion [4,5]. The chemical bonding structure of such amorphous semiconductors can be divided into two subfields: the tetrahedrally bonded materials as a -Si based semiconductors mentioned above and the chalcogenide vitreous glasses (ChVG). In the last case the polymerization is caused by means of group VI elements: S, Se, Te. The ChVG structures have appropriate energy gaps, high photoconductivity, optical absorption coefficients, adhesion value and are very perspective for low-cost PhVS development [6]. This follows from the possibility to modify chemically the ChVG in such a way that their electrical and optical properties could be independently varied by adjusting the concentration of the modifying elements [7].

2. Some physical properties of ChVG

Let us point out some properties by which the ChVG are distinguished among other amorphous materials [8]:

- the ChVG is an adaptive material with high resistance to nuclear particle irradiation;
- physical and chemical properties of glasses and the amplitude of their irradiation-induced changes have strong correlation with component ratio;
- the ChVG can form the rectifying and photovoltaic contacts with metals.

At present there exist some theoretical approaches describing the above mentioned peculiarities of the physical properties of ChVG. As a rule, these approaches combine the conventional ideas of valences, chemical bonds, structural models and the many-particle theory methods [7 ÷ 10]. The basic theoretical assumptions of such approach are as follows:

- the non-organic polymers are the materials with discrete metastable state sets;
- any of these states is determined by either homopolar and heteropolar chemical bonds ratio, or so called Mullers structure units (s.u.) ratio, "color" atoms sets or topological peculiarities [11];
- the transitions between the configurationally-stable states can be stimulated by external factors (i.e. radiation, pressure, etc.).

Due to this energy capacity of a structural network, the possibility of various-type chemical bond realization and their transformations are taken into account. The possibility of introducing the Mullers s.u. whose reiteration reconstructs the structure of the ChVG [12] is of concern here too. The ground and the excited states of a glass differ in the homo- and heterobonds or topological complexes ratio. In the ground state, the binding energy of the glass has the lowest value. The process of heterobond destruction and the formation of the same number of homopolar bonds are treated as the excitation process. This approach may be named as the "ball with knitting needle" model and is now in the focus of investigators attention. Such theory explains the main feature of the nuclear particles irradiation treatment of ChVG:

- the extreme composition of ChVG is determined by the chemical composition, breaking bonds concentration and s.u. ratio;
- ChVG can accumulate the energy of irradiation under the structural transformation;
- heat pump effect: ChVG can transform the radiation energy into the thermal one under the constant radiation fields.

Let us turn now our attention from the physics to the practical areas, where the amorphous semiconductors have a wide variety of potential applications. Here we shall point out the possibility to realize the ChVG-based amorphous graded band-gap films with a high structural stability and low concentration of darling bonds. In the amorphous graded bandgap structures one can realize the large component ratio value gradient and built-in fields to separate the photo-induced charge carriers. The ChVG can be deposited onto any substrate with non-epitaxial heterostructural junctions. They also lend themselves to relatively low cost fabrication over large area and thin film elements, which is necessary for electronics and PhVS applications. Another technological advantage of such mate-

rials is the elasticity of their physical constants due to imperfections in the close-packed atomic networks of their random chemical bonding structures. This explains high resistivity of amorphous semiconductors to the nuclear particle irradiation.

3. PhVS-multi-layer structures

In this report we present the results of the development and investigation of ChVG based PhVS multi-layer structures. High technological ability of ChVG films allows the new classes of functional structures to be realized by means of the amorphous graded bandgap structure synthesis in different directions. The types of the ChVG based multi-layer structures are as follows:

- the z -structures: matter composition gradient is realized normally to the surface;
- the $(x-z)$ -structures: matter composition gradient is realized along the surface and normally to it;
- the $(x-z)$ -multi-layer gradient structures.

The matter composition gradients in the multi-layer structures are presented schematically in Fig. 1.

We have synthesized and studied the multi-layer gradient $A < M(x,z)_n >$ -like structures, where $A = (As, Sb)_z S_3$, $As_2 Se_3$, $M = Al, Sn, In, \dots, n$ is a number of modifier layers.

Experimentally, the $(x-z)_n$ structures were obtained when the matter composition gradient was realized along the surface and normally to it. This was made possible by periodical mixing

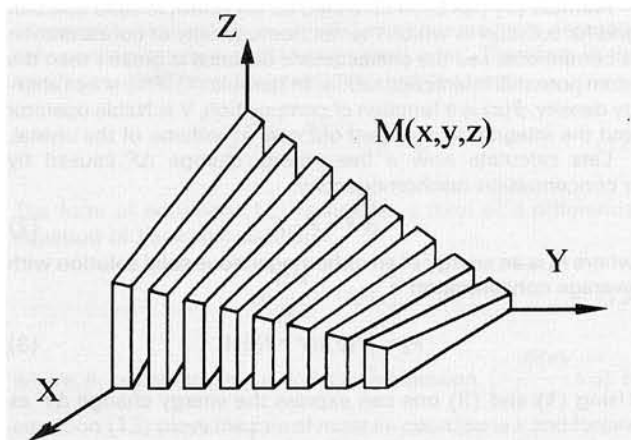


Fig. 1. The schematical modulator-matter composition dependencies in the structures

Fig. 2. Spectral dependencies of the photo-e.m.f. for the As-S based photo-voltaic structures: with 3 (curve 1) and 8 (curve 2) modulating layers

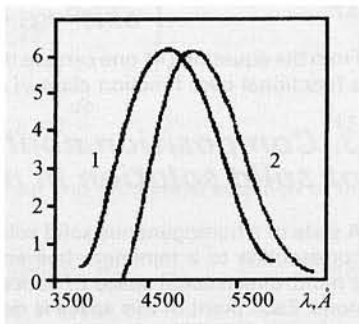
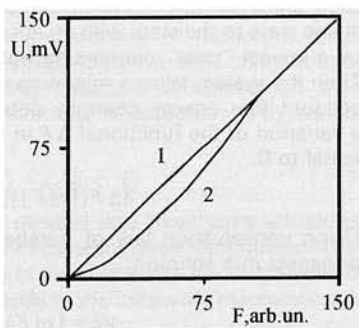


Fig. 3. The lux-volt characteristics of electron irradiated (EI) 8-layer PhVS: without EI (curve 1) and under EI (curve 2)



of the basic material. This results in the different bulk $(x,z)_n$ dependencies of photo-e.m.f. (e) and internal (dark) resistance, (r). The modulator layer thickness was about $200 \div 300 \text{ \AA}$. The samples for the photo-electrical studies were of sandwich-type with semitransparent or strip-like electrodes made from different metals or ITO (SnO_2, In_2O_3 composition). They were prepared on glass or lausanne substrates with total thickness of about $1 \div 2 \text{ mm}$ and samples cross-section of $2 \div 4 \text{ cm}^2$. It has been found that the photovoltaic parameters are determined by the matrix modifier material combination, modifier gradient value and the modifier layers number [13].

For example, Fig. 2 shows those data for the spectral dependencies of the photo-e.m.f. Some criteria for the optimization of matrix modulator material combination [14] and the equivalent electrical scheme of the $(x-z)_n$ -structure were presented in [15]. We found out that the sign and the value of the photocurrent are determined by the ratio of gradients of photo-e.m.f. to the internal resistance. We have investigated the resistivity of the $(x-z)_n$ -structures to the nuclear particle irradiation using the electron accelerator (microtron M-30) at the following operating parameters: $1 \div 25 \text{ MeV}$ accelerated electron energy; $v = 10^{-10} \text{ el/cm}^2 \text{ s}$ flux density, the radiation field homogeneity was not worse than 30%. The $(x-z)_n$ PhVS was exposed to the 10^{16} el/cm^2 flux at 18 MeV accelerated electron energy, $\varphi = 10^{11} \text{ el/cm}^2 \text{ s}$. It has been shown that irradiation slightly influences the spectral dependence of the photo-e.m.f. and the lux-volt characteristics (Fig. 3). For some compositions and parameters of the $(x-z)_n$ ChVG-based structures, the photo-e.m.f. values can be improved after irradiation.

4. Conclusion

Thus, the $(x-z)_n$ non-organic (ChVG)-based structures are perspective for cheap PhVS production required in further investigations.

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