PHOTOCONVERTERS WITH HETERO-INTERFACE STRUCTURE FOR POWERFUL ELECTRICAL SYSTEMS

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INTRODUCTION

At present single crystalline silicon (*ñ*-Si) photocells (PC) with protective quartz (SiO_2) coatings are widely applied to energy provision of autonomous and mobile objects during long-time operation in rigid conditions of the Earth and outer space. However, their use has been revealed by a number of serious lacks. They are (1) low conversion efficiency of PC (12-17 %); (2) shallow *n-p*-junction in *c*-Si-photocells, which collapses while being in service in extreme conditions of thermo-cycling, erosive influence on the PC surface of chemically active atoms and molecules, meteorite streams, charged electrization, rigid UV and irradiation; (3) optical properties of SiO_2 protective coating are not optimum and moreover become worsened under the influence of rigid UV [1].

The application of cascade system from photo-voltaic materials with the different optical performances is considered as the most perspective technology of PC`s efficiency raising. The maximal efficiency can be reached in silicon hetero-photocells with multiinterface structure, providing the creation of cascade distribution of band-gap (E_g) in the semiconductor material. The frontal surface in such heterosystem should have the width band-gap structure (E_g ~ 4 eV), while for other structures the quantity E_g must consecutively decrease. For exception of losses of low-energy quantums, the least value of E_g must be small. For PC silicon the least E_g is determined by *c*-Si(Al)-structure (E_g ~ 0,8 eV). The sharp hetero-junctions in material bulk are realized only under the condition of changing crystalline structure on width of ~ 20 angstrom. The creation of such crystalline interface structures with sharp (δ) transition layers by traditional chemical and diffusion methods is not possible. Using radiation methods of crystalline structure disordering of hydrogenated *c*-Si-photocell can be solve this problem. In such disordered structures it is possible to achieve the electrostatic fields $E > 10^4$ V/cm. The formation of amorphous-crystalline interface structures with gradient distribution in semiconductor bulk provides the creation of strong pulling electrostatic (δ-BSF)∇E_g fields

$$E = (-\nabla E_g)/q, \qquad (1)$$

where *q*-is an electron charge. The width of photo-convertors 0,5-1 mm is necessary for the full absorption of solar radiation in monocrystal silicon. It allows to execute (*c*-Si)-photocells with deep *p-n*-junction and to protect it from destroying influence of electrization in outer space conditions. Besides, such hetero-system from amorphouse-crystalline structures allows to use the broad range of solar spectrum (UV, visible light, short-range IR-radiation) with high intensity of quantum fluxes. These electrostatic fields will create the directional motion of minority charge carriers in *c*-Si heterostructure with deep *p-n*-junction (see Fig. 1). In this case the dimensional distribution of charge carriers (CC) will not depend on their diffusion length. The coefficient of CC assembly and internal quantum yield of photoionization determine spectral characteristic of photoconverters. The throughput capacity of frontal PC plane in the short-wave range of solar spectrum increases at formation of both width band-gap *a*-SiC:H structures and polycrystalline diamond coatings (*poly*-DC). The CC photogeneration in long-wave range of solar spectrum increases by multiple luminous flux passage in semiconductor bulk. This process is provided by texturization of frontal *c*-Si matrix surface and creation of reflecting back contact plane. The conversion efficiency of *c*-Si-hetero-photocell at execution of these technological features can be increased up to 40%. Such photoconverter with deep *p-n*-junction and diamond coatings will be protected from destroying influence of environmental activity.

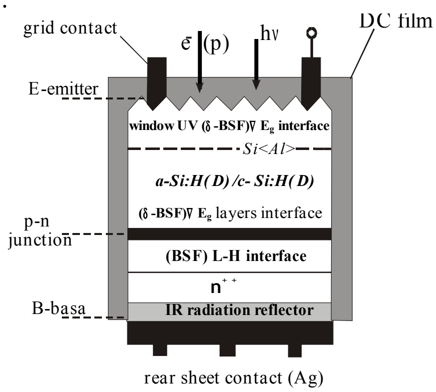

Fig.1. *c*-Si-heterophotocells with transformed structure.

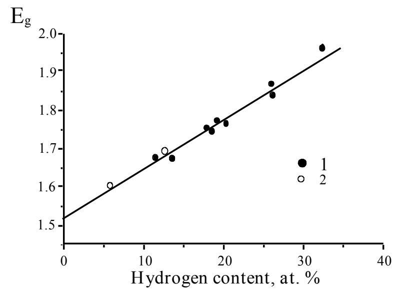

Fig.2 Dependences of width optical gap Eg on hydrogen concentrations in *a*-Si film: 1- deposited film, 2 - annealed film [3].

FORMATION OF AMORPHOUS CLUSTERS IN *c*-Si SEMICONDUCTOR BULK

The presence of localized states continuum is the main particularity of amorphous semiconductors. The long-range order in *a*-Si materials is absent, but the short-range order is maintained by presence of the chemical bond. The *a*-Si structure is characterized by randomly lattice with a covalent binding of atoms. The absence of the long-range order causes both the diffusion of fundamental absorption edge and appearance of tails of both valence zone and conduction band. It is note, the state of amorphous clusters in crystal lattice is metastable. For their stabilization in order to conservations of the dimensional disordering in crystalline matrix is used hydrogenation method. The concentration of chemically connected hydrogen atom influences a degree of a disordering structure, that it determines the energy magnitude of optical gap, Eg. The dependence E_g on concentration of hydrogen atoms in *a*-Si materials is shown in fig. 2. As following from presented data, the E_g value is increased up to ~ 1,8 eV in *a*-Si structure while the growth of hydrogen concentration is reached value up to 20 at.%. The photons absorption coefficient for *a*-Si structure under condition of direct quantum transition is:

$$\alpha(\lambda) = B^2 \ (h\nu - E_g)^2/h\nu, \qquad (2)$$

where $B = 700\ eV^{-1/2}\ cm^{-1/2}$. The α value for UV is $\sim 10^6$ cm^{-1} that is on the order more than in *c*-Si structure. Doping the *a*-Si:H materials by boron (B) does not cause the degeneration processes, as it has a place in c-Si matrix, but creates a new structure defects which are to be eliminated.The formation of disodering clusters in silicon is observed under irradiation by high-energy particles when a primary knocked out atom get the energy $E_0 \ \geq 5$ keV. In the case of electron irradiation the primary energy of particles should be as $E_e \ \geq 10$ MeV. The disordered ranges represent local defect clusters with the size 100-1000 angstrom. These clusters are surrounded by a layer of space charge and are blocked by fluxes of charge carriers. The point defects are being created only in the case when a recoil energy of atom is below 5 keV (threshold energy of disordered structures creation). The irradiation of silicon crystals is being carried out by intensive electron beams with energy $E_e \ \geq 20$ MeV up to doses 10^{-3} displacement per atom (dpa) at temperature 450 K. The formation of *ñ*-Si(Al) structures is being created by the method of nuclear microdoping using the bremsstrahlung gamma-quantums with energy E > 25 MeV and irradiation dose up to 10^{-5} dpa [2]. The *p*-type of electrical conductivity of *c*-Si(B) semiconductor is being saved during gamma-irradiation. As the irradiation dose increasing, the number of nonradiating recombination centres in the semiconductor increases and the CC concentration and their mobility is being decreased. Hydrogenation of *c*-Si matrix, which is necessary for both stabilization of amorphous clusters and neutralization of recombination centres, is carried out by two methods - (i) isostatic pressing treatment of the semiconductor in the temperature range 300-800 K and pressure up to 100 MPa; (ii) irradiation by hydrogen-helium plasma up to dose 1.10^{17} cm^{-2}. In such hydrogenated material the time (t) of radiation defects neutralization and formation of (*a*-Si:H)-structures in dependence on the annealing temperature T(K) is being described by equation [4]:

$$t = t_0 \exp (1{,}6\ 10^{-19}\ \varepsilon_a /kT), \qquad (3)$$

where ε_a - activation energy (1,18 eV); $t_0 = 10^{-11}$ s for (Si:H)-compound. The hydrogen distribution and their concentration in volume of such material determines the distribution profile of *a*-Si/*c*-Si interface structures in a matrix and the intensity of pulling electric (δ-BSF)∇E_g fields, respectively.

FORMATION OF OPTICAL WINDOW ON THE FRONTAL PHOTOCELL PLANE

The heterosystem consists from band-gap *poly*-DC (E_g = 5,5 eV) and *a*-SiC:H (E_g = 3,5 eV) structures is formed on the photovoltaic material surface in order to increase the throughput capacity of the frontal photo-converters plane in the short-wave range of solar spectrum. The formation of *poly*-DC-structures with properties like natural diamond is realized by CVD method in dense hydrogenous plasma of UHF-resonator with E_{011}- wave mode. Specifity of texturization, creations of *a*-Si and diamond coatings on the frontal photocells plane does not allow the polutions of their surface. At the working gas 99% H_2+ 0,7% CH_4+ 0,3% O_2 the synthesis temperature of fine-grained *poly*-DC can be decreased up to 725-925 K by sensibilization oxygen of reaction [5].

The texture formation on *c*-Si-matrix surface is realized by a laser irradiation in intensive fluxes of UHF hydrogenous plasma. The 30 MW power of laser irradiation with a pulse length in 15 ns is required for melting of silicon shallow layer by thickness of 0,2 microns. The detraping hydrogen during a solidification of hydrogenated shallow layer deforms it and creates blisters with sizes which are close to a wave length of visible spectrum and IR-radiation. These blisters are scattering the incident photons and increasing a passage trajectory of light and its general absorption. The continuous back contact of photocell intensifies the radiation reflection and by that increases its full internal absorption in the photocell emitter. The texturization of the frontal surface causes a short-circuit current increasing. The interferograms of a laser radiation are used for measurements of film thickness and blisters sizes during the texturization.

The pulling electrostatic fields for majority charge carriers (BSF)L-H in plane base of *n*-*c*-Si(P)-photocell are being created in structure of n-n^+-type. The methods combination of radiation-induced disordering structures, CVD and laser irradiation allows to advance a new technologies for creation of silicon photo-converters with high conversion efficiency in a broad range of waves lengths of solar radiation. The protected silicon photocells from irradiation, charged electrization, temperature and mechanical influences will allow considerably increase their operation resource in conditions of high-intensive fluxes of solar radiation.

REFERENCES

1. S. Bailey, H. Curtis, K. Long, Proc. of 2-nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, Vienna, Austria, 6-10 July, 1998 (in press).
2. A. N. Dovbnya, V. P. Yefimov, S. V. Yefimov Using beams technologies in development of photocells for solar batteries spacecrafts. Problem At. Sci. Technol. 1(28) (1997) p. 58. (in Russian)
3. A. Madan, M. P.Shaw. The Physics and Application of Amorphous Semiconductors. M.: Mir, 1991, 670p.
4 A. N. Dovbnya, V. P. Yefimov, S. V. Yefimov, Radiation transformation of photovoltaic materials structure, Problem At. Sci. Technol. 1(73), 2(74) (1999) p. 143.
5. A. N. Dovbnya, V. P. Yefimov, S. V. Yefimov, Formation of width band gup a-SiC:H(D)/ c-Si(B):H(D) interface structure and diamond coatings in (c-Si)-photocells, 14th Int. Conf. on Ion

-Surface Interactions (ISI-99), Zvenigorod (Moscow), Russia, 30 Aug.-3 Set. 1999, (in press).