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Fototermoplastic effect In the p-Si–n-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ structure

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Abstract*: One of the promising areas of photovoltaic and heat power engineering is the development of highly efficient photothermovoltaic (FTV) systems for converting the thermal energy of heated bodies into electrical energy. They have important advantages over other thermal power devices. It is known that for many semiconductor devices heating affects negatively their operation but for a photothermovoltaic element it increases its efficiency. In this work we studied the process of the appearance of voltage and electric current in the p-Si – n-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ structure at it is uniformly heated both in the dark and in the light. Upon uniform heating of the p-Si – n-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ heterostructure, both in the dark by heat and photo heating, and in light by solar radiation an electric current and a potential difference were generated in it. In the studied temperature range the dark current generated by photoheating has three orders of magnitude greater than in the case of thermal heating. However the potential difference generated by photoheating slightly decreases with increasing temperature but its value is almost two orders of magnitude greater than in the case of thermal heating. There is also a slight decrease in the photocurrent and potential difference at increasing temperature. Since the composition of the substrate – film intermediate region changes continuously from Si to the n-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ epitaxial film, it is a graded-gap layer with a smoothly varying composition that prevents breaks in the energy zones of the p-n structure . Due to the variability in the intermediate region, an energy barrier arises, mainly for holes, which contributes to the appearance of an additional separating field determined by the gradient of the band gap of this layer. Therefore in this structure the hole current caused by photothermally generated electron-hole pairs can be significant up to higher temperatures. The low efficiency of the studied structure is obviously associated with the recombination of the main parts of the photothermogenerated charge carriers.*

keywords: liquid phase epitaxy, thermovoltaic effect, photothermalvoltaic effect, solid solutions, heat generation of currents and voltages.

1. Introduction

One of the most promising areas of photovoltaic and thermal power engineering is the development of highly efficient photothermovoltaic (PV) systems for converting the thermal energy of heated bodies into electrical energy. They have important advantages over other thermal power plants. They have no moving parts, which extends their service life. It is known that for many semiconductor devices, heating negatively affects their operation, and for a photothermovoltaic cell, it helps to increase its efficiencywithti.

It was shown in [1] that when a polycrystalline Si solar cell is heated in the dark, an electric voltage and current arise in it, and their values monotonically increase with increasing temperature. A similar phenomenon was also observed at *the p–n*junction obtained on a sun-fused sisample . However, when a solar cell made of monocrystalline silicon was heated, there was no appearance of electric voltage and current in it. Therefore, the increase in the current with increasing temperature was explained by the manifestation of an impurity теthermovoltaicовольтаического effect at the grain boundaries of polycrystalline silicon. The advantages of teRMoelectric elements associated with the implementation of the impurity teRMovoltaic effect are discussed in [2-4]. These phenomena are observed on a wide variety of materials: samarium sulfide [5-12], zinc oxide [13, 14], copper (II) oxide [1-5], and semiconductorbinary compounds IIIII-V, which have n-type conductivity and are grownaccording to the methodChochralsky [11-6], mecrograined silicon [17], in films of a varizonal continuous silicon–germanium solid solution Si_xGe_{1-x} [18-20], sandwich structures[21], $Bi_2Te_{3\ alloys}$[22].

In this paper, we studied the process of potential difference and electric current generation in *p*-Si–*n*-$(Si2_2)_{1-x-y}(Ge_{Ge2})_x(ZnSe)_y$ structurese when it is uniformly heated both in the dark and in light.

2. Samples and experimental methods

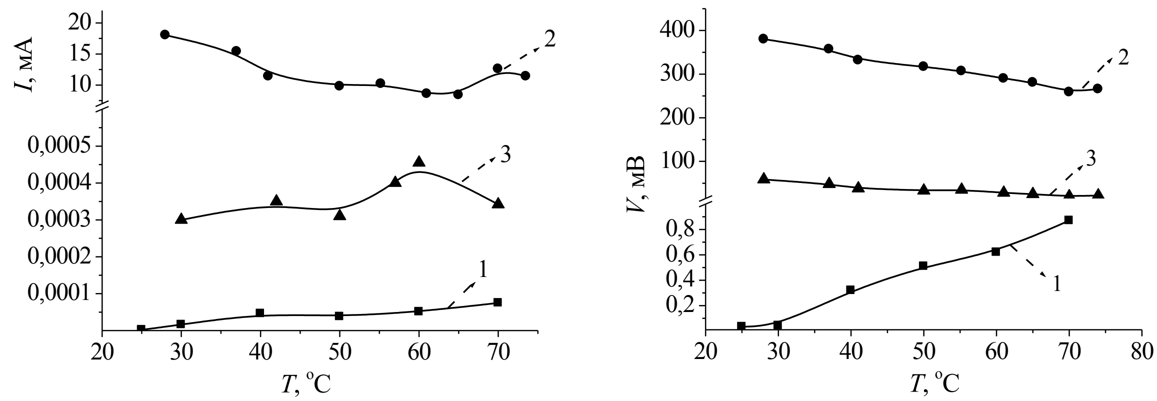
The structures were prepared by growing solid solutions of n-$(Si2_2)_{1-x-y}(Ge_{Ge2})_x(ZnSe)_y$ on *p* -Sisubstrates by liquid-phase epitaxy from a limited volume of tin solution–melt according to the technology described in [19-20]. The single-crystal Si substrates had a crystallographic orientation (111). The composition of the solution-melt was calculated from the data previously studied for the Si-Ge-ZnSe-Sn system and from the special literature [21]. The growth of the layers was carried out by forced cooling in an atmosphere of palladium-purified hydrogen. The forced cooling rate in the optimal mode was 1 deg/min. Solid solution layerswere crystallized in the temperature range of 95.0-750 °C. Current-collecting contacts attached to the structures were obtained from silver by spraying it in a vacuum. The contacts were solid on the back side and quadrilateral with an area$^{\text{of 4 mm2}}$ on the film side. The Si substrates were ~ 400 microns thick, and the epitaxial films were 15 microns thick. The grown epitaxial films also havean electronic type of conductivity.

Homogeneous heating of the studied structure was carried out in two ways: 1) thermal heating in the dark - was carried out using a tungsten spiral located inside a metal (stainless steel) container of cylindrical shape. The container was mounted inside a special cryostat, which made it possible to obtain a vacuum of up to 10^{-2} PA. The samples were mechanically tightly attached to the container. When electric power was applied, the spiral heated the container and the sample was heated through it. 2) photonheating - was carried out on a special copper container in sunlight under AM-1 conditions in the open air.

The output signal was removed from two ohmic contacts using pressure electrodes for current removal. The temperature of the sample was measured using a thermocouple attached to the end face with contacts.

3. Experimental results and discussion

When гетероструктуры *the p*-Si–*n*-$(Si2_2)_{1\ -x-y}(Ge_{Ge2})_x(ZnSe)$ y heterostructure was uniformly heated$_y$, both in the dark by thermal and photo heating, and in light by solar radiation, an electric current and potential difference were generated in it. According to the termo- and photodermatology current and potential difference heterostructures on temperature is shown in Fig. 1. Curve 1 in Fig.1 corresponds to the thermally stimulated current and potential differencethat occurs when the thermal heating of structure in the dark, curve 2 – photodermatology current and potential difference when heated, the structure of the solar rays, and curve 3 – thermally stimulated dark - current and potential difference in vodonagreval structure, but after the closing of the light.



a) b)

Fig. 1. The dependence of the generated electric current () and voltage (b) heterostructures *p*-Si–*n*-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ temperature during homogeneous: 1 – thermal heating in the dark; 2 – illumination by sunlight in conditions of AM-1; 3 – heating by solar radiation after shading structure.

As can be seen from figure 1, the generated dark current and potential difference (curves 1 (a) and (b)) increase rapidly from the beginning and then from 40 to 70 when the structure is heated warmly°C is experiencing slow growth. In the studied temperature range, the dark current generated by photonheating (curve 3 (a)) has an order of magnitude greater value than in the case of thermal heating. But in this case, the value of the dark current is practically independent of the temperature. However, the potential difference generated by photonheating (curve 3 (b)) decreases slightly with increasing temperature, but its value is almost на two orders of magnitude greater than in the case of thermal heating (curve 1 (b)). And there is also a slight decrease in the photocurrent and potential difference (curves 2 (a) and (b)) with increasing temperature. This may be due to a decrease in the height of the potential barrier of the separating field of the p-njunction with increasing temperature.

The generation of electric current and potential difference in structures in the dark under uniform thermal and фотонагревephotoheating is probably due to the impurity heat-voltage effect. Since the studied p-njunction consists of a p-Si substrate and an n-layer of an epitaxial $(Si2_2)_{1\ -x-y}(Ge_{Ge2})_x(ZnSe)_y$film, the depth of the separation barrier is determined by the thickness of the n-layer and is ~ 15 microns. The current is determined by nonequilibrium charge carriers generated near the region adjacent to *the p-n*junction. In this region, the main component of the solid solution $(Si2_2)_{1\ -x-y}(Ge_{Ge2})_x(ZnSe)_y$ is Si, and Ge and ZnSe act as an impurity with a small concentration. Ge_{Ge2} and ZnSe molecules create nanodefectscontaining covalent Si-Ge, Si-Zn, and Si-Se bonds [22]. Such bonds can form impurity energy levels located in the band gap of silicon [21], some of which are located in the upper part of the band gap. When heated, it is possible to generate electron-hole pairs with the participation of these levels. Under the action of the p-njunction field, these carriers participate in the creation of an electric current.

On the other hand, pas the composition of the transition region of the substrate–film interface is changing continuously from Si to epitaxial film of n-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$, then it is a graded gap layer with a gradually changing composition and prevents the occurrence of energy bands gaps of the p-n-structures. Due to varizonity, an energy barrier appears in the transition region, mainly for holes, which contributes to the appearance of an additional separating field determined by the gradient of the band gap of this layer: $\frac{1}{e}\left(\frac{dE_g}{dx}\right)$. As the temperature increases, the ability to separate electrons by the p-n junction field decreases, but for holes it is preserved up to higher temperatures. Consequently, in this structure, the hole current due фототеплото photogenerated electron-hole pairs can be significant up to higher temperatures. The low efficiency of the studied structure is obviously related to the recombination of the main parts of the photoplastics ofthegeneratedcharge carriers.

The difference on one and two orders of magnitude the values temnogo current and potential difference, respectively, in the case of a homogeneous heating of the *p*-Si–*n*-$(Si_2)_{1-x-y}(Ge_2)_x(ZnSe)_y$ heterostructures heat and vodonagreval evidence manifestation fototermoplastic effect in the studied structure. The detected effect requires further investigation. With the appropriate optimal selection of materials and the appropriate structure design, it is possible to increase the efficiency of current generation and potential difference with uniform heating of the structure.

4. Conclusions

Thus, the experiments confirm predictions of the theory that in semiconductors with non-uniform composition even when a little homogeneous warmed upve (ranging from 25-30°C) or фотоthermal excitation generates currents and voltages. At the same time, when the sample is exposed to sunlight and heated, the effect increases by more than an order of magnitude compared to the effect that occurs during thermal heating in the dark. In conclusion, I would like to emphasize that we are talking about studying the properties of a completely new material of a solid solution $(Si2_2)_{1\ -x-y}(Ge_{Ge2})_x(ZnSe)_y$ with a continuous change in composition along the length of the sample. This material has properties that distinguish it from both silicon and germanium and zinc selenide, which is very important for photo-thermoelectric conversion. In addition, skilful use фотоof the photovoltaic effect discovered in itрмовольтаического, i.e., a properly selected combinationтермofphotovoltaic effects should lead to an improvement in the usual photovoltaic characteristics of elements.

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