A Solar Cell, Based on the Epitaxial Layers of $A^{III}B^{V}$ Compounds, Transferred from the Substrate onto the Flexible Polymeric Carrier

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***Abstract* – An inverted GaAs solar cell structure has been grown with the MBE method. Together with the substrate, the structure was glued to a polymer film of polyethylene terephthalate (PET film) by means of epoxy resin. After the removal of the substrate, the contact platforms were created and the light window was opened. Research of the solar cell photovoltaic properties was conducted at non-concentrated sunlight with the AM 1.5D spectrum. The obtained efficiency equal to 16.65%, taking into consideration the absence of the antireflection coating and a grid of contacts on the face of the solar cell, says about its high degree of efficiency.**

***Index Terms* – MBE, solar cell, flexible carrier, $A^{III}B^{V}$ compounds.**

I. INTRODUCTION

TWO CLASSICAL semiconductor solar cells are silicon and gallium arsenide solar cell, as the widths of silicon and gallium arsenide band gaps are optimal for the solar spectrum on the earth and in the near-earth space [1]. In terrestrial conditions, the silicon solar cells has become most popular as a transformer of solar energy into the electric energy as it is much cheaper than gallium arsenide solar cells. The gallium arsenide solar cells has become most popular in space use as it has a little higher efficiency than that of the silicon solar cells, which is the most important criterion for space and, besides, it is more radiation-resistant, which is, undoubtedly, also an important criterion for space. However, not single-cascade (based on one element), but multi-cascade solar elements are already used in space (tandem), which allow a more efficient transformation of solar radiation into electric radiation; therefore, their efficiency is higher than that of the single-cascade [1]. At present, practically all solar cells created for satellites and other spacecrafts are grown up on a germanium substrate [2]. But they have several disadvantages. First, it is a high price of a germanium substrate, second, high specific weight of a germanium substrate, third, smaller efficiency compared with the InGaAs/GaAs/InGaP structure [3] and, fourth, lack of flexibility of such solar cells. The second and third disadvantage requires some explanation. High specific weight of a germanium substrate is disadvantage because the price of delivery of 1 kg of weight to the near-earth space orbit is very high. Therefore, the weight of a solar cell is of very great importance. As for the loss of efficiency, compared to the InGaAs/GaAs/InGaP structure, here, the thing is that the Ge cascade, when irradiated by solar spectrum, gives a small output voltage and a large output current compared to GaAs and InGaP cascades, but the total current of the multi-cascade solar cell is determined by the smallest current in one of the cascades. Therefore, the output current of the solar cell will be equal to the output current of GaAs and InGaP cascades. The use of InGaAs instead of Ge, can increase the output voltage of this cascade due to a higher band gap width. To maximize the efficiency of the solar cell, the percentage of In and Ga and, accordingly, the band gap width of InGaAs should be chosen such that the output current of the InGaAs cascade could coincide with the output currents of GaAs and InGaP cascades.

However, when creating the InGaAs/GaAs/InGaP solar cell, there is a problem that InGaAs has a lattice constant different from GaAs and InGaP and, as a consequence, with the growth of the GaAs/InGaP layers, the dislocations begin to form in them, and that greatly decreases the resulting solar cell efficiency. This problem can be solved using the so-called inverse metamorphous growth, i.e., if these layers are grown in the inverse sequence: InGaP/GaAs/InGaAs. Then the dislocations will occur only in the InGaAs layer, which brings the smallest contribution to efficiency. After the inverted structure is grown, it must be transferred to a carrier to get the correct sequence (InGaAs/GaAs/InGaP) of layers. A polymer polyethylene terephthalate film (PET film) was chosen as a carrier for a solar cell structure because, firstly, it is strong enough, secondly, flexible enough and, thirdly, cheap enough. After the structure is transferred to the flexible carrier, a substrate on which this structure was grown was removed. This procedure can be carried out either by full etching the substrate by placing it in an appropriate etchant or using epitaxial lift off (ELO) technology, whereby the sacrificial layer is etched and the substrate is cleaved from its grown epitaxial layers. Thus, applying ELO technology, the growth of the next solar cell is made on the same substrate, that is a big plus because this technology saves the expensive material of a GaAs substrate. The last step of this technique is the formation of contact areas and opening of the light window. This procedure is performed using etching respective areas of the structure. As a result, it is possible to obtain a solar cell whose efficiency

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will be higher than that of Ge(substrate)/GaAs/ InGaP solar cell and that will be deprived of all the above-mentioned disadvantages of a germanium substrate.

As the aforeformulated technique of creating solar cells is under development, this work is confined to the transfer of epitaxial layers of only a single-cascade GaAs solar cell grown on a GaAs substrate and transferred to the PET film. It should also be noted that the removal of the GaAs substrate occurred without ELO technology, i.e., the substrate was completely etched.

The aim of this work was to develop the basic operations of the epitaxial layers transfer technique and measurement of photovoltaic characteristics of the resulted solar cell, as well as determine its efficiency.

II. Experimental Results

First of all, by MBE method, a single-cascade GaAs solar cell was grown in the plant on a gallium arsenide substrate. The sequence and composition of the obtained structure are given in Tab. 1.

TABLE I
PROFILE STRUCTURE OF A GAAS SOLAR CELL

#	Material of the layer	Thickness	Doping level, cm^{-3}	Destination of the layer
9	GaAs:Be p^{++}	600 nm	$1*10^{19}$	subcontact
8	GaAs:Be p^{+}	50 nm	$5*10^{18}$	barrier
7	GaAs:Be p	2 µm	$1.7*10^{17}$	base
6	GaAs:Si n^{+}	100 nm	$2*10^{18}$	emitter
5	InAlP:Si n^{+}	30 nm	$8*10^{18}$	barrier
4	InGaP:Si n^{+}	5 nm	$8*10^{18}$	stop-layer
3	GaAs:Si n^{++}	1 µm	$1*10^{19}$	subcontact
2	InGaP i	70 nm	i	stop-layer
1	GaAs:Si n^{+}	250 nm	$2*10^{18}$	buffer
	GaAs(001) n^{+}			substrate

Route of the technological process of GaAs solar cell structure's transfer onto the PET film begins with etching mesa under contact platform to layer #3 of epitaxial structure. Further on, indium buses are formed on the obtained platform and the surface of layer #9 (see Fig.1).

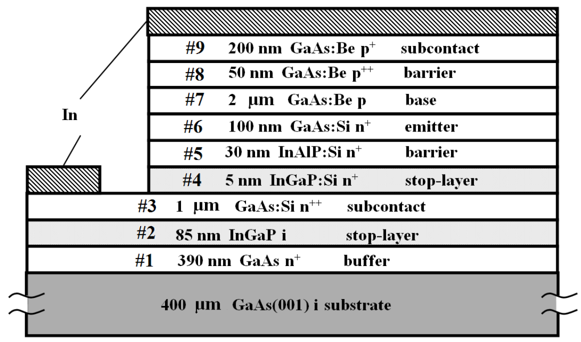

Fig.1. Profile of the GaAs solar cell structure prepared for gluing onto the PET film.

Then the structure is glued onto the flexible carrier, i.e., onto the PET film. Gluing is carried out by means of epoxy resin. As a result, the object, which scheme is given in Fig. 2, turns out.

Further on, the GaAs substrate is removed using an etchant. Then the contact platforms are etched out and released. The last step of this technique is the formation of the light window by means of etching layers #2 and #3 (see Fig. 3). The grid of contacts and the antireflection coating were not created. Demounting the charge carriers during measurement was carried out from the layer #9 and the subcontact layer #3 which encircled the light window along the perimeter.

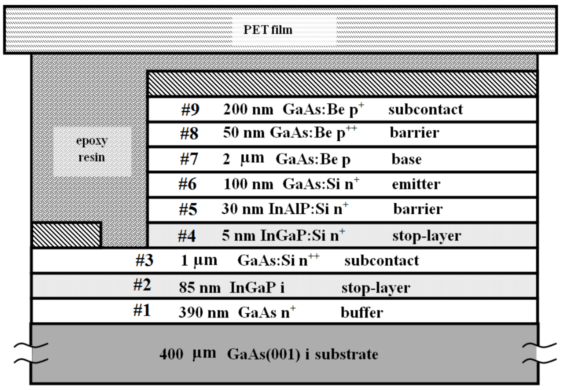

Fig.2. Profile of the GaAs solar cell structure glued onto the PET film.

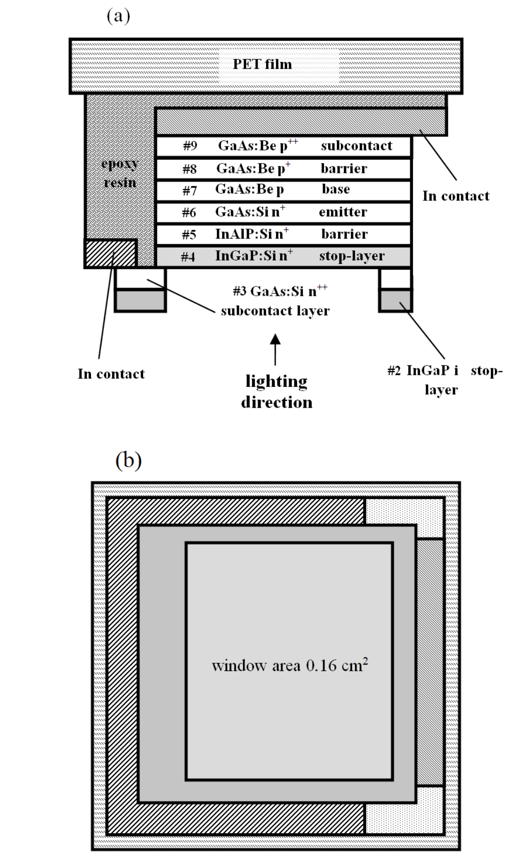

Fig.3. Cross-sectional diagram (a) and the face (b) of the solar cell, transferred onto the PET film.

After that, photovoltaic characteristic of the turned out solar cell was measured at non-concentrated sunlight with 0.1 Watt/cm^2 power density and AM 1.5D spectrum. The current-voltage characteristic of this solar cell is presented in Fig. 4. Next, the efficiency of this solar cell was calculated as a ratio of the maximum output electric power to the input power of the incident solar radiation, multiplied by 100%.

$$Eff = \frac{P_{output(\max)}}{P_{input}} \times 100\% = \frac{I_{\max.p.} \times U_{\max.p}}{P_{input}} \times 100\%$$

$$Eff = \frac{3.33 * 10^{-3} * 0.8}{0.1 * 0.16} \times 100\% = 16.65\%$$

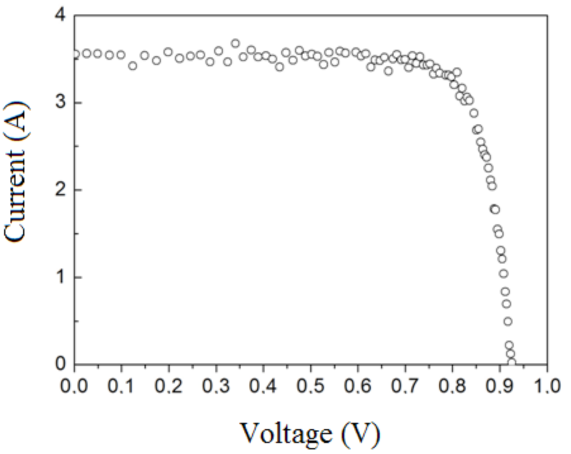

Fig.4. The CVC of a GaAs solar cell, transferred onto the PET film.

III. Conclusion

A possibility of creating an efficient solar element by means of transferring epitaxial layers of $A^{III}B^{V}$ compounds onto a polymeric polyethyleneterephthalate film (PET film) is demonstrated in this work. The obtained solar cell efficiency equal to 16.65%, taking into consideration the absence of the antireflection coating and a grid of contacts on the face of the solar cell, says about its high degree of efficiency. When using the antireflection coating, it is possible to reach an approximately 25% increase of portion of the absorbed photons in the photoactive solar cell layers - which will also lead to a 25% efficiency increase, respectively. As a result, the efficiency will be 20.81%. It is known from literature that when solar cells are illuminating with non-concentrated sunlight with the AM 1.5G spectrum, the currently set world efficiency records for the Si and GaAs solar cell are 25.6% [4] and 27.6% [5], respectively. When solar cells are illuminating with the AM 1.5G and AM 1.5D spectrums, the difference of its efficiency is minimal. It means that we obtained the solar cell that has a fairly high efficiency, herewith it may become higher than 20.81% if a contact grid is applied on the face of the solar cell.

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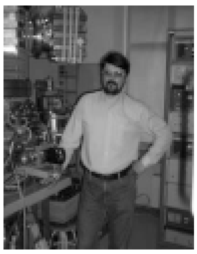

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