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# Formation Technology of Graded-Gap $Al_xGa_{1-x}As$ Solar Cell Structure Separated from GaAs Substrate

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Formation technology of graded-gap GaAs-$Al_xGa_{1-x}As$ sollar cell structure separated from GaAs substrate is developed. The technology composed of mechanical polishing and multi-step wet chemical etching enables to produce mechanically robust, comfortable to apply without special precautions solar cell. Open wide-gap surface obtained smooth ($R_a$ < 21 nm) around the active area for the structure with additional GaAs stop-layer. The supporting frame formed in the perimeter of the structure protects it from a bend. The formation technology does not impair electrical properties of the grown epitaxial structure.

*Keywords*: graded-gap $Al_xGa_{1-x}As$ structure, sollar cell, selective etching.

## 1. INTRODUCTION

Integration of electronic devices based on III-V materials with foreign substrates or supporting films which can be selected on the basis of their material properties rather than crystal growth demands opens the way for the development of various device structures[1 – 4]. As a special case the integration of high efficiency solar cells with light weight substrates is of direct interest for space applications and stacks of two or three solar cells with different bandgaps. Severe problems caused by lattice-mismatch and difference in thermal expansion coefficients still inhibit the development of heteroepitaxial growth of high quality materials. Often, these devices are made by homo epitaxy and substrate is removed subsequently mechanically or by etching. The epitaxial lift-off technique, allows for the separation of a III-V device structure from its GaAs substrate using selective wet etching of a thin $Al_xGa_{1-x}As$ ($x > 0.6$) release layer using an aqueous HF solution. This is a complicated method which requires a controllable external force applied to the film via the flexible carrier during the etch process [5]. Integration has to be accomplished by mechanical stacking of the thin film device with a foreign substrate, which causes a number of technical problems. Handling and alignment of the fragile thin film devices (1 μm – 10 μm thick) needs special precautions and Ohmic contacts have to be obtained at low temperatures.

This paper presents the formation technology that enables to produce mechanically robust graded-gap GaAs-$Al_xGa_{1-x}As$ sollar cell structures separated from GaAs substrate.

## 2. EXPERIMENTAL DETAILS

Multilayer graded-gap GaAs-$Al_xGa_{1-x}As$ solar cell structures were grown on GaAs substrate by liquid phase epitaxy process using „wipigless“ horizontal sliding boat system. Ramp-cooled growth technique was used. This technique is usual and the most reliable for the graded-gap GaAs-$Al_xGa_{1-x}As$ structure growth. Al fraction ($x$) in the wide gap side near GaAs substrate was 0.4 and decreased to 0 at narrow gap side in the graded-gap $Al_xGa_{1-x}As$ layer. Therefore, substrate must be removed in order to open the wide gap optical window. Substrate thickness was 350 μm and the photo-sensitive structure was only few μm in thickness, so the etching system must be carefully selected and process strictly controlled. Two types of multilayer structures: with an additional GaAs stop layer (Fig. 1, a) and without it (Fig. 1, b) were used for the investigation.

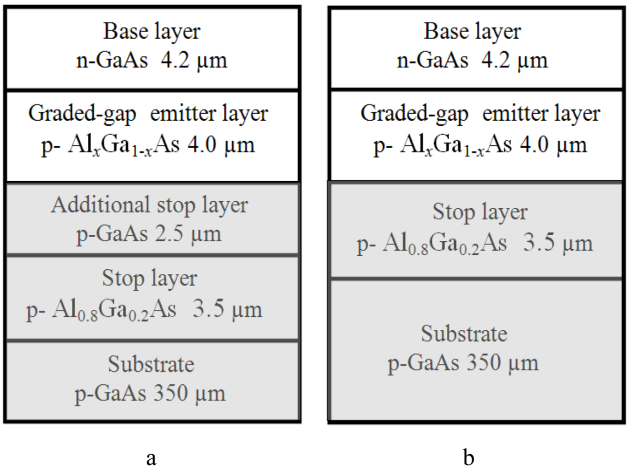


**Fig. 1.** Epitaxial multilayer graded-gap GaAs-$Al_xGa_{1-x}As$ structures with additional GaAs stop layer (a) and without it (b). The substrate and stop layers were removed in the active area of the structures during formation process. Removed parts of the structures painted in gray

Solar cell sample preparation was composed of mechanical lapping, ohmic contact formation and several chemical etching steps. First, substrate was mechanically polished to a thickness of (150 – 170) μm using Logitech 1WSB7 bonding system and 1AL54-1precision lapping and

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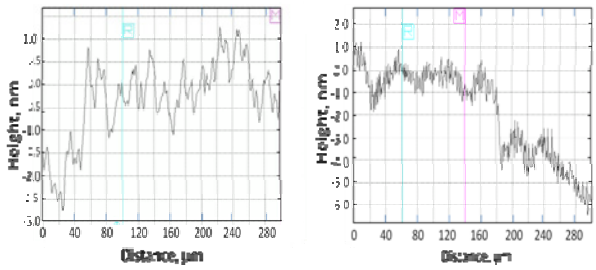
polishing machine. Substrate thinning is necessary because the subsequent need for a deep chemical etching which could damage the photoresist mask. This thickness is sufficient to ensure the strength of the structure that a next technological operations could be carried out comfortably. Roughness of the polished surface was measured with profilometer Dektak 6M. The surface texture of the GaAs substrate and the polished surface is shown in Figure 2. Surface roughness parameters $R_a$ (the arithmetic average deviation from the mean line) for the GaAs substrate and polished surface are $R_a$ =4.1 nm and 3.1 nm. This indicates good quality of the polishing process.




a b

**Fig. 2.** Surface texture of GaAs substrate (a) and polished GaAs surface (b)

Ohmic contacts were formed on both surfaces of the graded-gap GaAs-$Al_xGa_{1-x}As$ structure. Au-Ge-Ni and Cr-Au contacts were evaporated on *n*-type and *p*-type surfaces, respectively and annealed at 420 °C temperature in $H_2$ atmosphere. The contact on *p*-type surface was formed on the GaAs substrate area where it was planned to leave the supporting frame. Then the substrate was divided into separate rectangular solar cell samples The lower part of the sample was covered with 8 µm – 12 µm thick polyimide film and a small open area for the contact connection was formed. It is worth to note that the polyimide film is not resistant to the etchant containing HF acid. The structure was glued to the silicon plate. Photoresist mask covering the support frame and blocking metal contacts was formed and deep chemical etching was carried out using the dynamic etching method. The etching was stopped when the $Al_{0.8}Ga_{0.2}As$ stop layer was reached in any part of the sample area. This moment has been observed visually from the color change of the etched surface and is shown in Fig. 3.

The etching systems based on $H_2SO_4 : H_2O_2 : H_2O$ and $HNO_3 : H_2O_2 : H_2O$ solutions were tested for the etching uniformity and surface smoothness. For large area samples, flat and smooth ($R_a$ = 7.2 nm) deep-etched surface achieved using solutions containing nitric acid and that is better than in the case of sulfuric acid etchant.The crucial problem arising from the use of sulfuric acid etchant is resulting from convex surface of the sample. Deeper places at the supporting frame edges were observed in this case. Nitric acid etchant forms relatively flat surface around the etched area. Nevertheless, the stop layer is typically uncoveres in a small area at the corner of the etched surface near support frame. GaAs substrate residues of up to 10 µm thickness always remains in the uncovered area of the sample after deep etching. These substrate residues are removed by selective GaAs etching. Ammonium hydroxide ($NH_4OH$) and citric acid ($C_6H_8O_7$) solutions with hydrogen peroxide were tested as a selective etchant. Improved surface smoothness was obtained using citric acid etchant. In this way, the $Al_{0.8}Ga_{0.2}As$ stop layer was uncovered throughout the sample area. This stop layer was easily removed by selective etching in fluoride acid (HF). As is well known, HF is a selective etchant for $Al_xGa_{1-x}As$ where $x > 0.4$. In our structures $x = 0.4$ at the surface of $Al_xGa_{1-x}As$ emitter layer which must be open to light. Therefore, the emitter layer dissolution is observed in the structures without additional GaAs stop layer (Fig. 1, b). Low etching selectivity leads to deterioration of the surface smoothness and even deeper pits emergence on the surface of the emitter layer. To prevent this, we have incorporated the additional GaAs stop layer into the grown structure, as shown in Fig. 1, a. This layer was selectively etched with citric acid and hydrogen peroxide solution, and that has significantly improved quality of the emitter layer surface. Figures 4 and 5 show the surface texture and the image of completely prepared solar cell sample. The parameter $R_a$ for prepared samples does not exceed 21 nm.

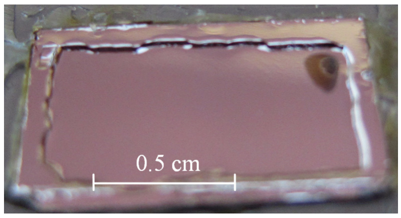



**Fig. 3.** The sample image of deep etching stop point. The uncovered area of $Al_{0.8}Ga_{0.2}As$ stop layer is seen in the upper right corner of the sample

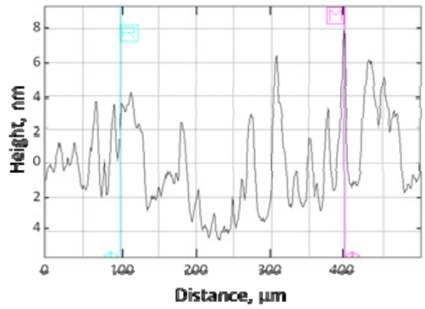



**Fig. 4.** The final texture of the emitter surface for the structure with the additional GaAs stop layer

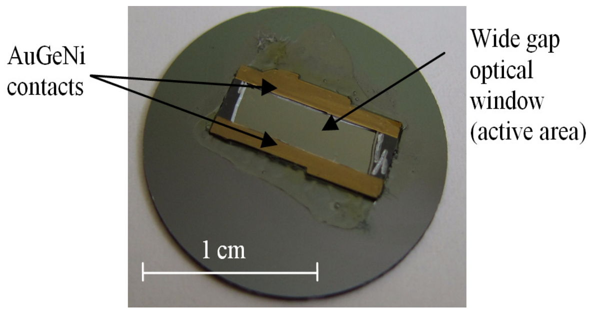



**Fig. 5.** The image of the completely prepared solar cell sample glued to a Si plate after the chemical etching processes

After chemical etching the sample was unsticked from the Si plate and Au wires were soldered to the contact areas. The sample was mechanically strong enough that we would be able to work without special precautions. It should be noted that the sample retains a tolerable strength without the protective polyimide film. The multilayer epitaxial structure bonded to the polyimide film without supporting frame is also can be made but in this case it has a tendency to bend.

## 3. RESULTS

Current-voltage (*I-V*) characteristics of the graded-gap GaAs-$Al_xGa_{1-x}As$ solar cell samples formed by using such technology process were measured outdoors on a sunny day. Solar cell samples did not have any antireflective coating. The results were compared with the simultaneously measured cascade-type solar cell sample characteristics (see Fig. 6).

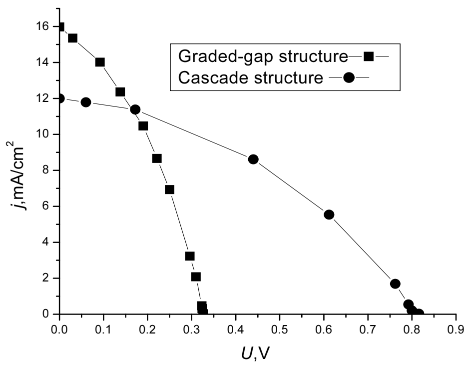



**Fig. 6.** Typical *I-V* characteristics of the graded-gap GaAs-$Al_xGa_{1-x}As$ and cascade-type solar cell sample under real Sun illumination.

The cascade-type solar cell structure was composed of *p*-type GaAs, $Al_{0.2}Ga_{0.8}As$, $Al_{0.4}Ga_{0.6}As$ layers and $p^+$-GaAs contact layer. The layers were grown on n-GaAs substrate in the above-named order. The $p^+$-GaAs contact layer was chemically removed in the active area of the sample. The band gap in the structure inreased in steps towards to the illuminated surface and p-n junction was formed deep in the narrow-gap region. As can be seen, the short-circuit current density ($j_{SC}$) of the graded-gap GaAs-$Al_xGa_{1-x}As$ solar cell sample reaches a value of $j_{SC}$ = 16 mA/cm$^2$ and exceeds the cascade-type sample current, which is about 12 mA. However, the graded-gap GaAs-$Al_xGa_{1-x}As$ structures are characterized by a low open circuit voltage $V_{OC} < 0.4$ V, but $V_{OC} = 0.84$ V is obtained for the cascade-type sample. The large leakage current was observed in *I-V* characteristics of graded-gap solar cell structures measured in the dark. In order to verify that the large leakage current is not caused by applied formation technology, *I-V* characteristics of structures were measured before removing the GaAs substrate. They also showed the large leakage current, that means the problem lies in the epitaxial GaAs-$Al_xGa_{1-x}As$ structure. Much lower leakage current was observed in the cascade-type structure. The obtained results show that the epitaxial structure needs to be improved, however developed technology can be applied not only to solar cells, but also for production of other devices requiring substrate removal.

## 4. CONCLUSIONS

The formation technology of graded-gap GaAs-$Al_xGa_{1-x}As$ sollar cell structure separated from GaAs substrate composed of mechanical lapping and multi-step wet chemical etching is developed.

The additional GaAs stop layer in the graded-gap GaAs-$Al_xGa_{1-x}As$ structure is necessary to form the smooth wide-gap surface of the active area.

The technology enables to produce mechanically robust, comfortable for applying without special precautions solar cell structure.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