Development of technology obtaining layers $A^3B^5$ compounds with variable bandgap for use in solar cells

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Abstract. Developed technology of obtaining layers with variable band gap by metalorganic vapor phase epitaxy (MOCVD). Made structure graded-gap layer with a thickness of 0.5 microns. Internal pulling electrical field the resultant structure was 5.8 kV/cm. In the resultant structure observed an increase circuit voltage due to the contribution of the gradient of the band gap.

1. Introduction

One of the main concerns was the issue of the energy crisis in the 21st century. One solution to the problem is to convert solar energy into electricity. Currently, photovoltaic cells with a p-n junction thin-film silicon-based have a maximum coefficient of performance (COP) ~ 20%. Difficult in the manufacture multijunction photovoltaic cells ~ 44.7%. One possible option the construction of photovoltaic cells is the use of smooth heterostructures. In these heterostructures, the band gap increases to the illuminated surface (Fig. 1.)[1].

In 1957, in a theoretical paper [1] it was shown that smooth heterostructure at high light levels photovoltage ($V_{EG}$) appears that when $b > \frac{\Delta E_g}{q}$ is similar to that bandgap difference. In such a heterostructure is broadening of the spectral characteristics of photosensitivity and better utilization of solar energy[2]. However, from 1978 to the present, were not carried out experiments on the production of graded-gap structures, due to the imperfection technology for production. Purpose of our work obtaining structures with variable band gap, the modern method by metalorganic vapor phase epitaxy.

2. Obtaining of solid solutions based on gallium antimonide (GaSb)

Model material was selected on the basis of a solid solution of gallium antimonide (GaSb). The lattice parameter coincides with gallium antimonide solid solution parameters, the quantity gap which lies in the range from 0.3 eV to 1.7 eV (0.7-4 microns) (Fig. 2.)[3]. At the beginning of our work, experiments were conducted to obtain solid solutions lattice-matched to GaSb with a band gap of 0.3 eV to 0.9 eV. All experiments were carried out on the installation phase epitaxy AIXTRON AIX 200.
Growth of solid solutions held at a temperature of $T = 600^\circ$ C and a pressure of $P = 100$ mbar. The flow of carrier gas (H2) was $F_c = 5$ l/ min. The source of arsenic (As) to a solid solution served - arsine (AsH3), the source of antimony (Sb) - trimetilsurma (TMSb). Ga source served - trietilgally (TEGa), served as a source of In - TMIn, served as a source of Al - trimethylaluminum (TMAl). The quality of the solid solutions has been examined by X-ray diffraction analysis (Fig. 3.) and photoluminescence (Fig. 4). Table 1. shows the compositions and the bandgap of the solid solutions.

Table 1. The bandgap of the obtained solid solutions

| №  | Solid solution           | Eg, eV |
|----|-------------------------|--------|
| 1  | InAs$_{0.91}$Sb$_{0.083}$ | 0.29   |
| 2  | Ga$_{0.07}$In$_{0.92}$As$_{0.89}$Sb$_{0.11}$ | 0.32   |
| 3  | Ga$_{0.58}$In$_{0.42}$As$_{0.40}$Sb$_{0.594}$ | 0.43   |
| 4  | Ga$_{0.79}$In$_{0.21}$As$_{0.12}$Sb$_{0.873}$ | 0.48   |
| 5  | Ga$_{0.848}$In$_{0.152}$As$_{0.096}$Sb$_{0.904}$ | 0.54   |
| 6  | Ga$_{0.85}$In$_{0.15}$As$_{0.11}$Sb$_{0.89}$ | 0.57   |
| 7  | Ga$_{0.923}$In$_{0.077}$As$_{0.072}$Sb$_{0.928}$ | 0.64   |
| 8  | GaSb                    | 0.72   |
| 9  | Al$_{0.016}$Ga$_{0.984}$As$_{0.005}$Sb$_{0.995}$ | 0.74   |
| 10 | Al$_{0.11}$Ga$_{0.889}$As$_{0.013}$Sb$_{0.987}$ | 0.84   |
| 11 | Al$_{0.197}$Ga$_{0.803}$As$_{0.024}$Sb$_{0.976}$ | 0.93   |
3. Obtaining of solid solutions with different gradient of the band gap and based on their structures.

![Fig. 3. XRD spectr of the sample (Eg = 0.57 eV)](image)

![Fig. 4. PL spectr of the sample (Eg = 0.57 eV)](image)

Table 2. The value of the gradients for different thicknesses

| d, μm | 1.7 | 2.2 | 3.4 |
|-------|-----|-----|-----|
| V_E, kV/cm | 1.7 | 1.3 | 0.85 |

Based on these results were identified technological modes of manufacturing graded-gap structure with a smooth change of the band gap of 0.43 eV to 0.72 eV, and different changes in the gradient of the band gap (Fig. 5). Profile of the band gap was calculated according to a study obtained by mass spectrometry of secondary ions (SIMS).

Based on these studies, the technology was developed and manufactured structure with graded-gap layer thickness of 0.5 μm (Fig. 6). The internal electric field pulling the obtained structure was 5.8 kV/cm (Fig. 7.). Fig. 7. shows the band diagram the obtained structure, the real and the assumption of fixing the valence band. The open circuit voltage in such a structure, it V_{oc} = 0.33 V (300 K), V_{oc} = 0.5 V (77 K) (Fig. 8.). Indicating that the increase in the open circuit voltage due to the contribution of the gradient of the band gap.

Fig. 9. shows the spectral characteristics structure under study in comparison with the structure of gallium antimonide. The comparison shows that the graded-gap structure of the obtained absorption spectrum is wider due to the narrow-band and the contribution of the gradient of the band gap.
4. Conclusion

Were identified technological modes of manufacturing graded-gap structure with a smooth change of the band gap of 0.43 eV to 0.72 eV, and different changes in the gradient of the band gap. Based on these studies, the technology was developed and manufactured structure with graded-gap layer thickness of 0.5 μm. The internal electric field pulling the obtained structure was 5.8 kV/cm.

The open circuit voltage in such a structure, it Uhh = 0.33 V (T = 300 K) Uhh = 0.5 V (T = 77 K). Indicating that the increase in the open circuit voltage due to the contribution of the gradient of the band gap. Due to the narrow-band contribution to the gradient of the band gap, there is a broadening of the absorption spectrum. A subsequent study is planned to expand the range of variation of the band gap of 0.43 to 1.2 eV.

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References

[1] J Tauc. Rev. 1957 Modern Phys., 29, chapter 3, p 308.
[2] Z I Alferov, V M Andreev and V I Korol'kov. 1978 Technical Physics Letters, 4, chapter 7, p 369.
[3] P A Houston. 1981 Journal of Materials Science, 16, 11, pp 2935-2961