AlGaAs/GaAs solar cell with CNT transport layer: numerical simulation

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Abstract. AlGaAs/GaAs solar cells (SC) was modeled. Conventional SC was compared with structure with the thinner emitter. SC with additional CNT transport layer was simulated and compared with SC without it. The simulation was carried out with different geometry of the contacts and light flux. CNT transport layer has allowed achieving an increase in SCs efficiency up to 1.7% compared with metal contact grid.

1. Introduction

The advantages of GaAs-based solar cells (SCs) is higher efficiency in comparison with Si-based [1] but they traditionally are used in aerospace and military applications because of their high cost. Moreover, new technology can be tested on single junction SC to further implementation in multi-junction SCs.

Today the efficiency of GaAs single-junction SCs is close to the theoretical limit due to last developments in optimization of the thin-film structure and epitaxial growth conditions. Therefore, the role of the contact layer in solar cells has increased. Contact layer determines the efficiency of charge carriers collecting and affects the absorption of the light. These factors have a direct impact on the SC efficiency which stimulates intensive research in this area. To reduce ohmic losses, it is necessary to increase the contact area, but it leads to an increase in shading area and a decrease in short-circuit current. Another way to reduce lateral resistance is by using a transparent layer with high conductivity, such as ITO, ZnO, CNT, etc.[2] In our previous work, it was shown that SCs with CNT layer can have better efficiency compared with other materials [3]. In this paper, we concentrate our attention on SC simulation with CNT layer.

The GaAs-based SCs often were used with light concentrator in order to increases open-circuit voltage and reduce square of the photoactive element due to its high cost [4]. Furthermore, CNT transport layer application can be more advantageous in the area of light concentrator SCs which use high currents thus conductivity of the upper layer becomes more important.
2. Calculation

A heterostructural AlGaAs/GaAs solar cell with CNT transport layer and metal contact grid have been modeled. The SC structure is presented on Fig 1. Since the electrical field component which is perpendicular to the growth direction, predominantly exist in the emitter and window, as well as transport equations in the first approximation, can be considered linear in the electric field, the model was separated into two parts: one-dimensional model of the semiconductor structure and two-dimensional model of the surface current spreading. Continuity equation and Maxwell equations were solved by the finite element method for one-dimensional simulation along the growth direction. The Shockley-Reed-Hole, optical and Auger recombinations were taken into account in our model [5] [6] [7] to computation current and voltage losses. Mobility model with velocity saturation was used to correct calculation in the high internal electrical fields such as in the p-n junction.

![Figure 1(a, b). SC structure (a) without transport layer; (b) with transport layer](image)

Anti-reflection coatings with near-zero refractive have been made by nowadays [8]. Therefore in our work only processes of light absorption and currents generating were consider in our research, the ideal anti-reflection was used.

In conventional CSs with only metal grid contacts, emitter thickness is about 0.5 um [9] [10]. Our simulation showed that in solar cells with CNT layer, using 30 nm thickness emitter is preferable. In table 1 are presented comparing of the recombination rate for structures with 30 nm and 400 nm emitter. It can be seen, that the total recombination rate is less in the structure with thinner emitter. For this reason, current in the structures with thinner emitter is greater and the efficiency consequently is greater too. In the structures without transport layer, the thicker emitter is necessary to provide sufficient lateral conductivity. In our structure lateral conductivity is provided by the transport layer. It can be seen on Fig 2.

![Table 1. Recombination characteristics of the modeled SCs](image)

|                      | SC with 30 nm emitter | SC with 400 nm emitter |
|----------------------|-----------------------|------------------------|
| Recombination rate in emitter | $1.68 \times 10^{14}$ s$^{-1}$ cm$^{-2}$ | $2.10 \times 10^{16}$ s$^{-1}$ cm$^{-2}$ |
| Recombination rate in base | $2.12 \times 10^{16}$ s$^{-1}$ cm$^{-2}$ | $1.15 \times 10^{16}$ s$^{-1}$ cm$^{-2}$ |
| Total recombination rate | $2.13 \times 10^{16}$ s$^{-1}$ cm$^{-2}$ | $3.25 \times 10^{16}$ s$^{-1}$ cm$^{-2}$ |
| Short-circuit current   | 27.35 mA cm$^{-2}$    | 25.66 mA cm$^{-2}$     |
Series of simulation with different contacts, CNT layers and light flux was performed. Efficiency dependency on light flux and contacts is presented on Fig 3. Figures 3(a) and 3(b) show the dependences for the cases of SC with and without CNT, respectively. The efficiency gain after adding CNT transport layer was 0.2% in case AM 1.5 spectrum and 1.7% in case of using 200 times light concentration. With decreasing the distance to contacts efficiency decline due to reflexion from the contacts. In the area of the graph with a bigger distance to the contacts, the efficiency decrease because of growing recombination rate inside the SC and decrease the effective working area of SC. The reason for this effect is a non-zero voltage drop due to lateral currents and consequently, increase the voltage to the values close to open-circuit voltage in the area which is far from contacts. The increased voltage leads to the growth of the recombination rate and rapid drop of the generated current density as it can be seen on Fig 4. The voltage and generated current density distribution is presented on Fig 5. Efficiency growth with increasing light flux explain by increase open-circuit voltage [9], moreover, there is opposite effect: currents magnification leads to increasing ohmic losses and for this reason optimal distance between contacts decrease. After 200 times light concentration for this reason efficiency declines.

Figure 2. Efficiency dependency on distance between contact

Figure 3(a, b). Efficiency dependency on distance between contact and light flux.

(a) SC with 98% transparency CNT  (b) SC without CNT
3. Summary

The GaAs/AlGaAs SC was modeled. Optimization of the one-dimensional model showed that emitter in SCs with CNT layer should be thinner than in conventional SCs. Although SC with thin emitter has insufficient conductivity, adding CNT layer solves this problem. Moreover, there is efficiency gain 0.2% in the case AM 1.5 spectrum and 1.7% in case of using 200 times light concentration despite absorption increases.

Acknowledgments

This work was carried out with the support of Skolkovo Institute of Science and Technology (Agreement No. 3663-MRA dated December 25, 2017), The Russian Federation President Council for grants (grant MK-1458.2019.2, SP-2324.2018.1), The Ministry of Science and Higher Education of the Russian Federation (grant 3.9796.2017/8.9, grant 16.2593.2017/4.6).

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