Current Distribution in GaAs Solar Cell with Carbon Nanotube Transport Layer

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Abstract. Numerical simulation and EBIC measurements of GaAs-based solar cells with metal grid and CNT transport layer were performed. Influence of CNT transport layer properties on lateral current distribution was analyzed. In accordance with electron beam induced current measurements it was shown that CNT demonstrates perfect transport properties leading to good charge carrier’s collection.

1. Introduction

The number of theoretical and experimental studies of the GaAs based solar cells (SC) efficiency improvement has significantly increased in recent years. It relates to approaching of the single junction photoconverters efficiency to their theoretical limit [1]. Thus, researchers have focused on ways how to increase the efficiency of solar cells by improving the properties of anti-reflective coatings and electrical contacts which determine the efficiency of charge carrier’s collection [2-3]. New various materials such as transparent metals and transparent conductive oxides, metal grids, conductive polymers, graphene, silver nanowires, and carbon nanotubes (CNTs) are being tested for this purpose.

CNTs are characterized with high conductivity and transparency. In addition CNTs have a wide direct band gap corresponding to the sun spectrum [4]. Excellent material properties, coupled with the ability to scale the material, ease of manufacture and low cost make CNTs an ideal photovoltaic material compatible with conventionally used planar A3B5 semiconductor structures. Due to a combination of unique properties, CNTs can act as a good alternative to metal contacts in a GaAs-based solar cell or can be used as a transport layer for charge carriers, reducing the area of the element covered with metal. The use of CNTs can reduce ohmic losses and shading of the active region in the SC.

Performed preliminary theoretical studies have shown that the joint use of metal grid and CNTs as a transport layer allows to increase the distance between the bars of the metal grid, which collect the
photocurrent [5]. In this paper we carried out the simulation of current distribution in SC with CNT transport layer and its experimental study.

2. Calculation
The current distribution for two-dimensional model solar cells with metal grid and CNT transport layer was numerically modeled. The simulation was carried out in Silvaco TCAD software. Optical recombination, Shockley-Reed-Hall recombination [6-7], Auger recombination [8] and mobility decrease during the motion of carriers in strong electric fields were taken into account in the model. The material parameters of layers depending on impurity concentrations were used in the simulation. The design of the simulated SC structure is presented in table 1. The simulation results for SC with metal grid and CNT transport layer are presented in Fig. 1a and Fig. 1b correspondingly.

| Layer  | Material   | Thickness | Doping type | Doping level (cm$^{-3}$) |
|--------|------------|-----------|-------------|--------------------------|
| Window | Al$_{0.7}$Ga$_{0.3}$As | 20 nm | p-type       | $2\times10^{18}$        |
| Emitter| GaAs       | 10 nm     | p-type       | $2\times10^{18}$        |
| Base   | GaAs       | 3 μm      | n-type       | $2\times10^{17}$        |
| Buffer | GaAs       | 200 nm    | n-type       | $2\times10^{18}$        |
| Substrate | GaAs      | 300 μm   | n-type       | $4\times10^{18}$        |

Table 1. Structure parameters of the SC

![Simulation results. Current distribution in SCs with metal grid (a) and CNT transport layer (b).](image)

It is clearly seen that in the case of sample with a metal grid, the lateral photogenerated current flows mainly through the wide-band gap window and the emitter, while in a sample with CNT, the current flows predominantly in the transport layer. The simulation results show that CNT provides the effective lateral transport of charge carriers.

3. Experimental
To study the effect of the CNT transport layer on current distribution and transport of the GaAs-based solar cell, two SC with different design were grown in this research by means of molecular beam epitaxy. To make the analysis of the CNTs influence straightforward we fabricated simple design GaAs SCs without the CNTs, which will be denoted as “basic”, and with the CNTs. The design of the cells was chosen similar to the one described in the literature [9].

Ni/AuGe back contact of both SC types was fabricated by thermal evaporation. Cr/Au metal grid on the front surface of basic SC was produced by combination of optical lithography and physical
vapor deposition. Single-walled CNTs for second type SC were obtained by the aerosol (floating catalyst) chemical vapor deposition method [10].

In order to investigate current distribution in SCs with the metal grid and CNTs, electron beam-induced current (EBIC) measurements were performed in Zeiss Supra 40 SEM microscope equipped with Gatan measurement system and software. The measurements were carried out at 5 kV beam acceleration voltage.

In Fig. 2a, b EBIC maps of the top surface of the metal grid and CNT SCs, correspondingly, are presented. In Fig. 2a one can see the pattern of the metal grid. Black area in Fig. 2b corresponds to the silver paste droplet for the current collection. According to the obtained experimental data, the EBIC signal induced by the generation of electron-hole pairs in the SC structure does not change along the surface not for the grid (Fig. 2c) neither for the CNT (Fig. 2d). SCs demonstrating that the both contacts are perfect in terms of ohmicity, surface conductivity and uniformity, allowing effective current collection from sq. cm area.

**Figure 2.** EBIC maps of the surface of the metal grid SC (a) and CNT SC (b) and corresponding EBIC signal scans along the designated lines (c, d).

4. **Summary**
The carried out simulation and EBIC study of the CNT SC demonstrates good electrical contact between the SC surface and the CNTs as well as perfect transport properties of the latter leading to good carriers collection. These properties together with a very technologically simple deposition method of the CNT contact layer makes this material a promising alternative to the SC contacts based on metal grid.

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