Solar cells based on GaAs and carbon nanotubes

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Abstract. This work is devoted to fabrication and characterization of a GaAs solar cell with a CNT top contact. The characteristics of a conventional solar cell with a metal contact grid and a solar cell with a CNT electrode were compared to demonstrate the benefits of a CNT based approach. The photoelectric properties of the solar cells were studied by measuring the IV characteristics and external quantum efficiency. The fabricated CNT solar cell showed better performance due to improved photocurrent collection efficiency. The demonstrated technology for the fabrication of CNT electrodes can be applied to a wide range of semiconductor photovoltaic devices, including flexible thin-film solar cells and solar cells based on nanowires.

1. Introduction

In recent years, theoretical and experimental studies of the possibilities of increasing the efficiency of solar cells (SC) based on GaAs have significantly increased in number. Obviously, this is due to the approximation of the efficiency of single junction photoconverters to their theoretical limit [1-2]. Therefore, the researchers focused on ways to increase the efficiency of solar cells by improving properties of anti-reflective coatings and electrical contacts, which determine the collection efficiency for charge carriers [3-4]. Currently, various new materials, such as semitransparent metals, metal grids, conductive polymers, graphene, silver nanowires, and carbon nanotubes (CNTs) are being tested for this purpose.

CNTs are characterized by high conductivity and transparency [5]. In addition, CNTs have a wide direct band gap corresponding to the solar spectrum, significant photoabsorption in the range from the infrared to the ultraviolet part of the spectrum, and high mobility of charge carriers contributing to their efficient transport. All of this makes CNTs an ideal photovoltaic material compatible with GaAs planar semiconductor structures. Thus, CNTs can act as a good alternative to metal contacts in a GaAs-based solar cell or serve as a transport layer for charge carriers, reducing the area of SC coated with metal due to a combination of unique properties. The use of CNTs can reduce ohmic losses and shading of the active region in the SC.

Theoretical studies have shown that the use of CNT as a transport layer allows you to increase the distance between the lines of the metal grid which collects the photocurrent [6]. At the same time, it is possible to increase the thickness of the lines, reducing the ohmic losses in them.
Today, there are many publications on the creation of solar cells with CNTs, however, CNTs are mainly used as an active layer of the Schottky structure [7–8]. In this paper the use of a transparent conductive layer of carbon nanotubes as a passive electrode for semiconductor solar cells based on GaAs has been studied.

2. Experimental
To study the effect of CNT contact on the efficiency of solar energy conversion, two GaAs-based solar cell structures were used. The basic structure of the SC (without CNT) was grown according to the method described in the literature [9-10]. The structure of the SC for creating a CNT contact is distinguished by a thinner emitter layer and a heavily doped window. SCs were grown by molecular beam epitaxy. To create a back contact to both structures, an Au: Ge alloy with a Ni sublayer was used. In the base structure, a facial contact was used in the form of a Cr/Au grid obtained using photolithography and vacuum deposition. In the second SC, a contact was used from randomly arranged single-walled CNTs obtained by the aerosol (floating catalyst) chemical vapor deposition method [11]. A 40 nm CNT’s layer with 90% transparency (at 550 nm) and ~ 50 Ω/□ sheet resistance was used in the experiment. Scanning electron microscopy (SEM) image of the CNT’s layer is shown in figure 1.

![SEM image of the CNT’s layer](image)

**Figure 1.** SEM image of the CNT’s layer (top view).

The current-voltage characteristics of the resulting SCs were measured by a 4-probe method at a probe station with a AM1.5G simulator of the solar spectrum flux (figure 2, (a)). The external quantum efficiency (EQE) of the SCs was measured using a setup based on a monochromator and a photodetector (figure 2, (b)).

The measurement results showed an efficiency increase of 0.86 % for solar cells with CNTs (11.51 %) as compared to solar cells with a metal contact grid (10.65 %). This increase was found to be due to an increase in the efficiency of current collection, which led to an increase in $J_{sc}$ from 16.92 to 17.86 mA/cm$^2$. The open circuit voltage and the fill factor are similar for both SCs (~0.95 V and ~67%, respectively). We observed increased EQE of the CNT SC compared to metallic grid contact SC in the whole spectrum, especially in $< 550$ nm wavelength range, which we associate with a thinner emitter layer. Indeed, highly doped emitter material can affect EQE due to recombination of charge carriers and reduced light absorption in the active layer. Also the EQE enhancement could be a manifestation of the CNT antireflective properties.
3. Summary
The fabricated CNT solar cell showed better performance due to improved photocurrent collection efficiency. The demonstrated technology for the fabrication of CNT electrodes can be applied to a wide range of semiconductor photovoltaic devices, including flexible thin-film solar cells and solar cells based on nanowires.

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