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Single Wall Carbon Nanotubes (SWCNTs) as (*i*) Type in the Photovoltaic Cell of Nano-Dimensions

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Abstract

In this paper, a new modified approach to design the photovoltaic cell has been presented by adding Single Wall Carbon Nanotubes (SWCNTs) as type (*i*). The main issue is to increase the efficiency of the photovoltaic cell, on the other hand, to exploit a larger range of electromagnetic wave frequencies, specifically a range within terahertz (THz) frequency domain, using 3D EM computer simulation technology (CST). It is clear in the normal PV cell start working at frequency of 500 THz, while the frequency at which the PV cell with SWCNTs operates is much less and it is close to zero, on the other hand, the PV cell with SWCNTs needs a larger cross-section area of 2800 nm^2 to operate at frequency of 500 THz. This cell can be easily produced industrially, which means increases the efficiency of solar cell.

Keywords

Single Wall Carbon Nanotubes (SWCNTs), Photovoltaic Cell (PV), CST Simulation

1. Introduction

The available energy resources are becoming significantly more interesting due to the need to produce green sources of energy. The energy that reaches the surface of the earth from the sun light is very huge. Today, the world uses this energy at 5.23% of the global energy consumption in various ways including the PV cell to produce electrical energy [1] [2]. There has been a keen interest in finding solutions for improving efficiencies in solar cells. The efficiency of the PV cell currently in circulation reaches to 33.16% [3]. The PV cell, whose internal structure consists of (P-N) type silicon alloy, operates at a wavelength in the range of (400 - 1100) nm [4].

Carbon Nanotubes (CNTs) are cylindrical large molecules consisting of a hexagonal arrangement of hybridized carbon atoms, which may by formed by rolling up a single sheet of graphene (single walled carbon nanotubes, SWCNTs) or by rolling up multiple sheets of graphene (multiwalled carbon nanotubes, MWCNTs) [5].

SWCNTs have been widely used in different fields of science and engineering applications including: novel memory devices [6], biosensors [7], telecommunications [8], photonics [9], high frequency transistors [10]. In particular, according to some properties such as their chirality dependent band gap, conductivity and chemical stability, have made them attractive to design a new solar cell with high efficiency [11] [12].

In many scientific papers related to the use of SWCNTs, these studies were limited to incorporating SWCNTs into the P-type and N-type to improve PV cell efficiency. There is significant interest in using single walled carbon nanotubes (SWCNTs) as type (*i*) material, which will not only improve PV cell efficiency but also increase the frequency range which operates the PV cell [13] [14] [15].

SWCNTs are doing the capture for charge carriers in one direction, so it will decrease the loss of energy that transfers to heat energy due to the collision between the charge carriers in the depletion region. If the length of the SWCNTs is in the nano-range, this gives an additional advantage to the PV cell as it happens to the charge carrier tanning and thus increases the number of charge carriers and this increases the efficiency of the PV cell [16] [17].

2. Methodology

A typical design for known PV cell has been designed using 3D EM computer simulation technology (CST), this PV cell is in three dimensions, in nanometers scale, and the dimensions are as the follows (50, 50, 50) nm. It used the silicone component to define the PV cell as P-type and N-type and the boundary for the PV cell is a vacuum, the source of the electromagnetic wave was a plane wave with frequency range of (1 - 1000) THz.

In this paper, a material structure is presented to design a new PV cell by adding the SWCNTs as (*i*) type between silicon alloys, it is required enhancement to increase the efficiency of PV cell. The difference between the PV cell in **Figure 1** and **Figure 2** is the addition of the SWCNTs as (*i*) type which its radius (2.71) nm. The SWCNTs is defined using the Durde model, in this model three important parameters will be defined which are: plasma frequency, collision frequency and density. This PV cell with SWCNTs has been designed using 3D EM computer simulation technology (CST) [7] [8].

3. Mathematical Analysis of SWCNT Composite Material

First step of modeling PV cell in nano scale at low frequency domain and then it

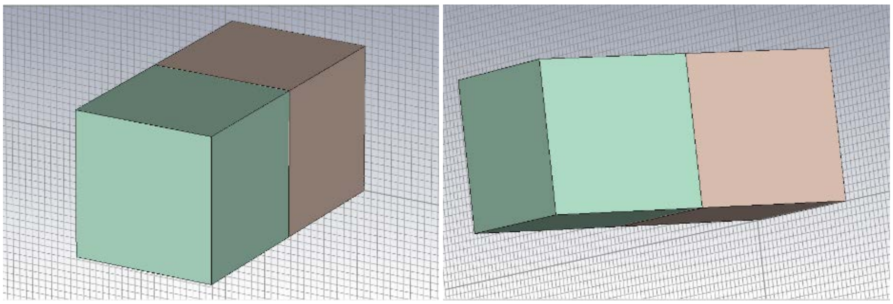

Figure 1. The 3D structure of normal PV cell (P-N) type.

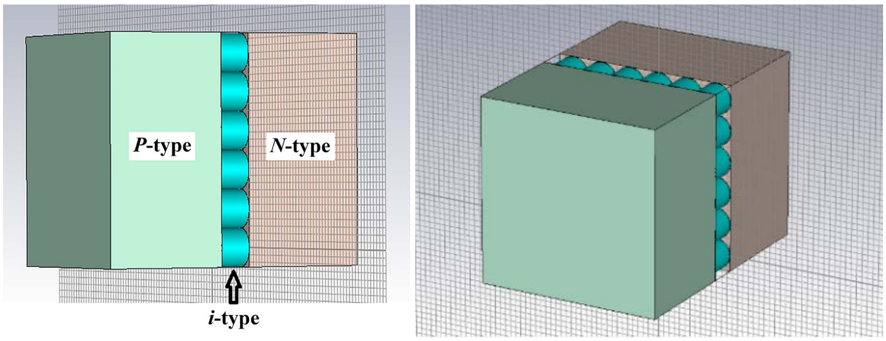

Figure 2. The 3D structure of PV cell with SWCNTs in depletion region as (*i*) Type.

has been modeling the SWCNTs to create CNTs on software package (CST), the method of defining SWCNTs by using Drude dispersion model.

Drude Dispersion Model

Drude's model is based on the kinetic theory of electrons in a metal which assumes that the material has motionless positive ion and non-interacting electron gas using classical mechanical theory of free electron to explain the transport properties of conduction electrons in metals, conductive oxides, and semiconductors [18].

4. Simulation Modeling Approach of New Material Structure

Through the previous approach, Drude dispersion model is adopted and effective parameters are calculated. Mathematical dispersion formulas in the Drude Dispersion model have been used to evaluate the material's optical properties by adjusting specific set parameters [14] [18] [19] [20]. The value of epsilon infinity is one for all types of CNTs. The value of plasma frequency for SWCNTs is computed from the following Equations:

$$w_p = \frac{2e}{\pi r}\sqrt{\frac{V_f}{\varepsilon_0 h}} \quad (1)$$

where, V_f is the Fermi velocity for CNTs, r is the radius of CNTs, and the collision frequency is considered as the same value of the relaxation frequency for SWCNTs from equation:

$$v = \frac{6\tau}{r} \tag{2}$$

5. Simulation Results and Discussions.

5.1. Operating Frequency of Normal PV Cell and PV Cell with SWCNTs as (*i*) Type

The frequency of the electromagnetic waves at which the PV cell operates is called the operating frequency. In order to be the PV cell more efficient it is important to increase the ability of the cell to exploit a wider range of wave frequencies. This section presents the simulation results of the scattered power for normal and proposed PV cell with frequency of the electromagnetic waves as shown in Figure 3 and Figure 4, respectively.

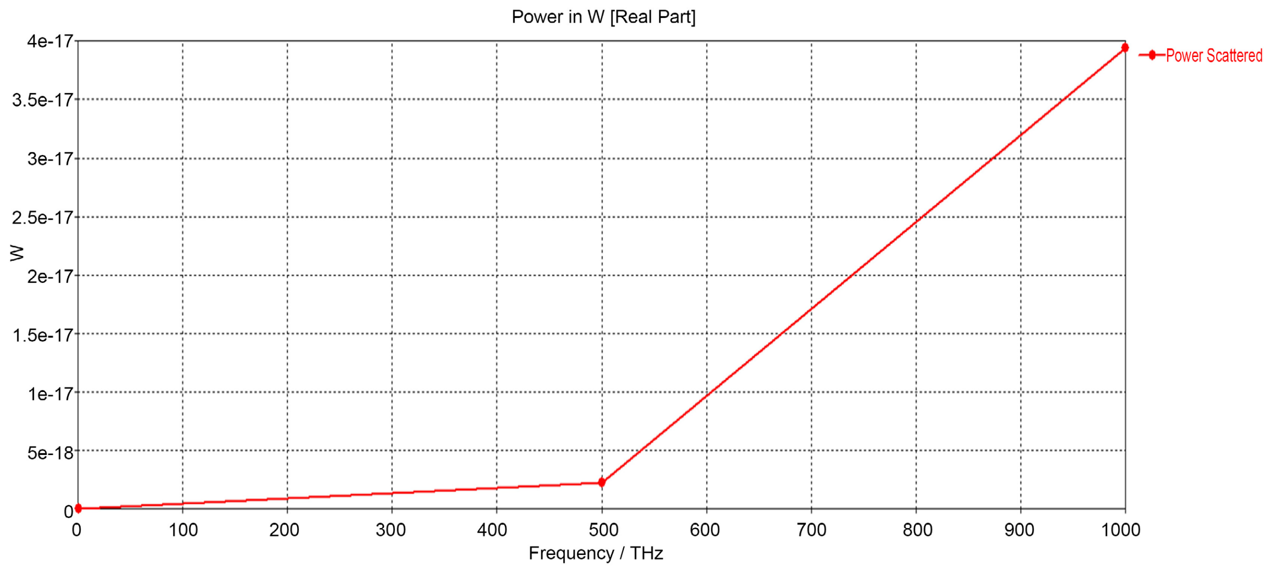

Figure 3. The scattered power in (Watts) in normal PV cell (P-N) type with frequency in (THz).

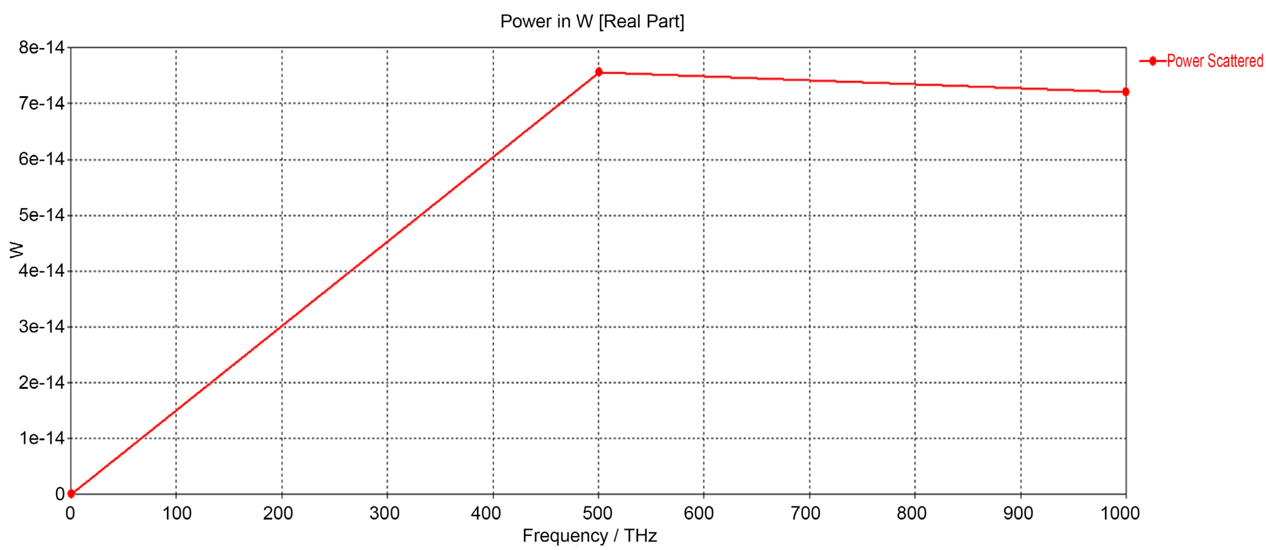

Figure 4. The scattered power in (Watts) in PV cell with SWCNTs with frequency in (THz).

Figure 3 and **Figure 4** show that how much the huge change of the scattered power at the frequency range of (0 - 500 THz) from ($0-3\times10^{-18}$ W) for normal PV cell while in PV cell with SWCNTs ($0-7.5\times10^{-15}$ W) which increased by a factor of 10^3. The amount of increasing of the scattered power means the increase in PV cell efficiency.

It is clear in the normal PV cell start working at frequency of 500 THz, while the frequency at which the PV cell with SWCNTs operates is much less and it is close to zero, which means that using SWCNTs as (*i*) type leads to more exploitation of the solar energy and thus increases the efficiency of solar cell.

It has been observed that above the frequency of 500 THz the behavior of the scattered power is constant, due to the dielectric lose effect, which means the loss of energy that goes into heating a dielectric material in a varying electric field, because the current carriers have the suitable amount of energy which is enough to path through the depletion region and the additional amount of energy convert into heat energy, as shown in **Figure 4**.

5.2. Cross Section Area with Operating Frequency

One of the results shown by using 3D EM computer simulation technology (CST) is that the PV cell has dimensions in nanometers. The frequency of the electromagnetic waves that operate on it varies according to the cross-section area as shown in **Figure 5** and **Figure 6**.

In this section presents the simulation results of the cross-section area with operating frequency of the normal and proposed PV cell. It is clear that in normal PV cell needs a very small cross-section area of about 20 nm^2 to operate at frequency of 500 THz, as shown in **Figure 5**. A PV cell of this size is difficult industrially to produce nowadays. However, the PV cell with SWCNTs needs a larger cross-section area of 2800 nm^2 to operate at frequency of 500 THz. This

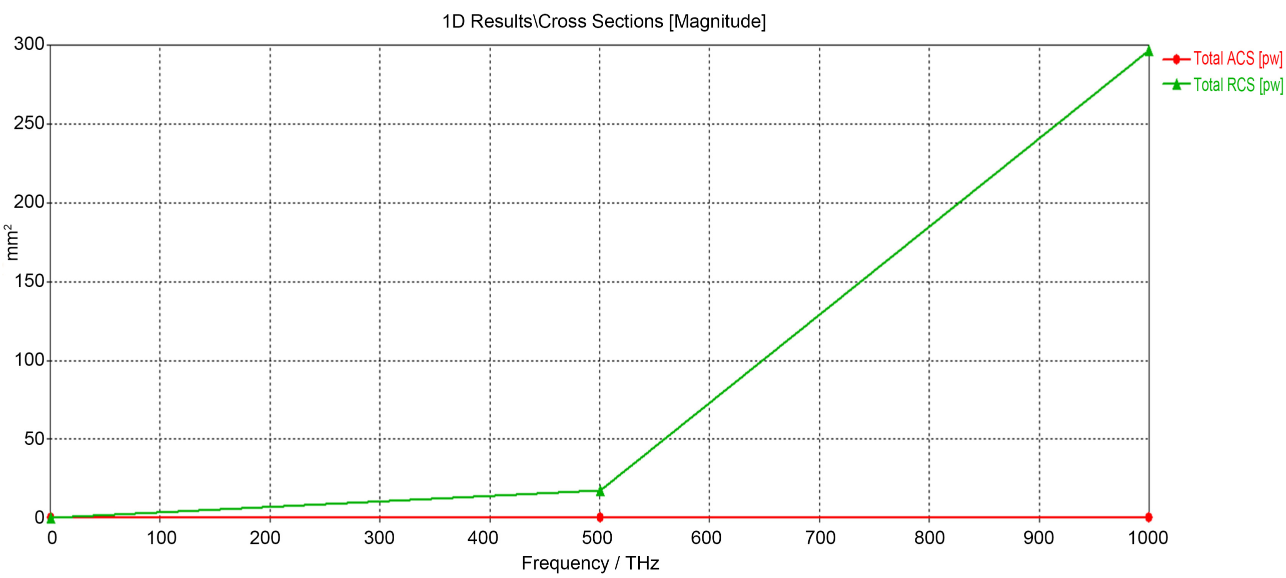

Figure 5. Cross section area in (nm^2) of depletion reign in normal PV cell.

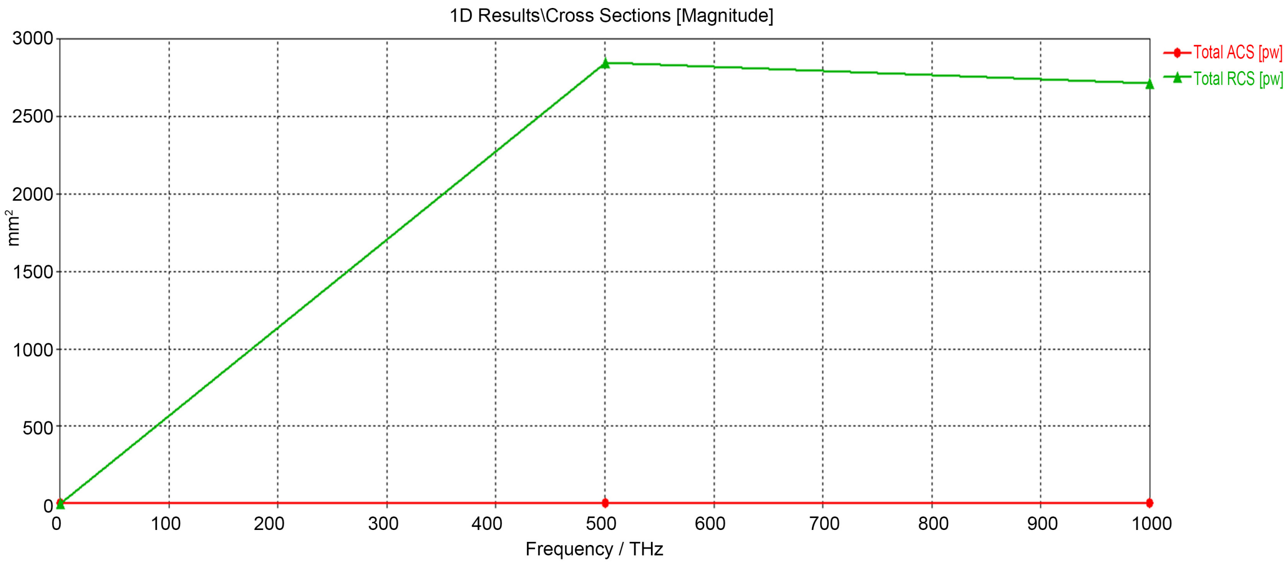

Figure 6. Cross section area (nm^2) of depletion reign in PV cell with SWCNTs as (*i*) type.

cell can be easily produced industrially, as shown in **Figure 6**.

6. Conclusions

In conclusion, we investigated the effects of adding the SWCNTs as (*i*) type in normal PV cell. A new design for PV cell by adding the SWCNTs as (*i*) type between silicon alloys was designed by using 3D EM computer simulation technology (CST). The result shows the huge change of the scattered power at the frequency range of (0 - 500 THz) for normal PV cell with SWCNTs which are increased by a factor of 10^3. Also, in the PV cell with SWCNTs starts working in low frequency, it is close to zero. On the other hand, the PV cell with SWCNTs needs a larger cross-section area of 2800 nm^2 to operate at frequency of 500 THz. This cell can be easily produced industrially. In future work, the aspiration is to optimize the aspect ratio (length to diameter) of SWCNTs to get the PV cell with higher efficiency values.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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