Improvement of Absorption Characteristics of Solar Cell above Room Temperature Using Quantum Dot

A. N. Alekhateeb[1], M. A. Rashid[2*], F. Malek[3], M. A. Humayun[4], A. Azmi[5]

School of Electrical Systems Engineering
University Malaysia Perlis, Pauh Putra Campus, 02000 Arau, Perlis, Malaysia.
[1]kalkateb2000@gmail.com
[2*]abdurrashid@unimap.edu.my
[3]mfareq@unimap.edu.my
[4]humayun0403063@gmail.com
[5]azralmukmin@unimap.edu.my

***Abstract*- This paper presents a theoretical study on the light absorption characteristics of solar cell. We have analyzed the temperature dependence of the absorption coefficient of light and the percentage of the incident light absorbed by the solar cell. We have investigated numerically these characteristics using Si and GaAs based quantum dot in the active layer of the solar cell. Numerical results obtained are compared. The comparison results reveal that the absorption coefficient of the solar cell has been increased significantly using GaAs based quantum dot in the active layer of the solar cell. Therefore GaAs has been proved to be the best alternative material to fabricate solar cell with higher absorption coefficient and higher light absorption rate in the upcoming decades.**

Keywords: Quantum dot, Absorption coefficient, Temperature, GaAs

I. INTRODUCTION

Solar energy is the cleanest form of energy available all over the world. We receive the solar energy in the form of light and heat [1]. Light has three unique properties namely absorption, reflection and refraction [2]. The working principles of optoelectronic devices are mainly dependent on these properties of light. Solar cell is an optoelectronic device that converts the solar energy directly into the electrical energy. The operation of solar cell is dependent on the absorption of light [3,4].

Semiconductor materials have a sharp edge in their absorption coefficient. The solar cell is usually placed in an open space to collect significant amount of light [5]. Therefore light of wide range of wavelengths incident on the solar cell. The light of different wavelength has different energy [6]. If the energy of the incident light is lower than the band gap energy of the semiconductor material it does not have sufficient energy to raise an electron across the band gap. As a result light is not absorbed [7]. The absorption coefficient depends on the material as well as the wavelength of the light which is being absorbed. If the absorption coefficient of a material is higher than that of others, the light absorption capacity of the material is also higher [8].

The solar cell is placed even in higher temperatures in space and concentrator systems. Hence temperature is considered as one of the main parameters that affects the solar cell performance significantly [9]. Therefore, the effect of temperature on the absorption properties of light has been given the top most priority in this present research work. We have analyzed these absorption and transmission characteristics of light in solar cell by using Si and GaAs based quantum dot in the active layer of the solar cell. The comparison results reveal that GaAs based quantum dot can be a potential material to fabricate the solar cell in the very near future.

II. MATHEMATICAL MODEL

The intensity of light transmitted through a layer of material with thickness x is related to the incident intensity I_0 according to the inverse exponential power law that is usually referred to as Beer-Lambert law [10]:

$$I = I_0 e^{-\alpha x} \tag{1}$$

where I is the amount of light transmitted through the material, I_0 is the amount of light incident on the solar cell and α is the absorption coefficient of the active layer material of the solar cell.

The absorption coefficient determines how far into a material light of a particular wavelength can penetrate before it is absorbed. Absorption coefficient is defined as:

$$\alpha = \frac{4\pi K}{\lambda} \qquad (2)$$

where λ is the wavelength and K is the Boltzmann's constant. If λ is in nm we need to multiply it by 10^7 to get the absorption coefficient in the units of cm^{-1}.

On the other hand, the wavelength is directly related to the bandgap energy of the semiconductor material used to design the solar cell. The relationship between the wavelength and the band-gap energy is given by the following equation.

$$E_g = \frac{hc}{\lambda} \qquad (3)$$

where $E_g$is the bandgap energy of the semiconductor material,h is the plunck's constant, c is the velocity of light.

Now from Eq. 2 and Eq. 3 we get the relationship between the energy band gap of the active layer material of the solar cell.

$$\alpha = \frac{4\pi K E_g}{hc} \qquad (4)$$

Again the temperature dependence of the direct band gap semiconductor can be described by Varshni's equation [11].

$$E_g(T) = E_g(0) - \frac{\gamma T^2}{T+\beta}. \qquad (5)$$

Where $E_g(T)$ is the energy band gap of semiconductor, $E_g(0)$ is the energy band gap at $T = 0$ K, γ and β are the Varshni's parameters of the semiconductor material. The bandgap and Varshni's parameters of Si and those of GaAs are given in table 1 [12].

TABLE I
Band gap and Varshni parameters of Si and GaAs

Material	$E_g(0)$(eV)	γ(meV/K)	β (K)
Si	1.166	0.473	636
GaAs	1.519	0.541	204

TABLE II
Parameters used for numerical calculation

Parameters	Value
Boltzmann's constant K	1.38×10^{-23} JK^{-1}
Planck's Constant h	6.63×10^{-34} JS
Velocity of light c	3×10^{8} mS^{-1}

III. NUMERICAL RESULTS

This section presents the comparative analysis of temperature dependence of the absorption coefficient of solar cell and the amount of light absorbed with temperature using Si and GaAs based quantum dot in the active layer of the solar cell. The Eq. 1 to Eq. 5 is used to calculate the absorption coefficient, the amount of light absorbed by the solar cell material. Then the amount of transmitted light was also calculated. The results obtained are shown in Fig. 1. To Fig. 3 The parameters used for the numerical calculation for InN and Ge are given in Table 1.

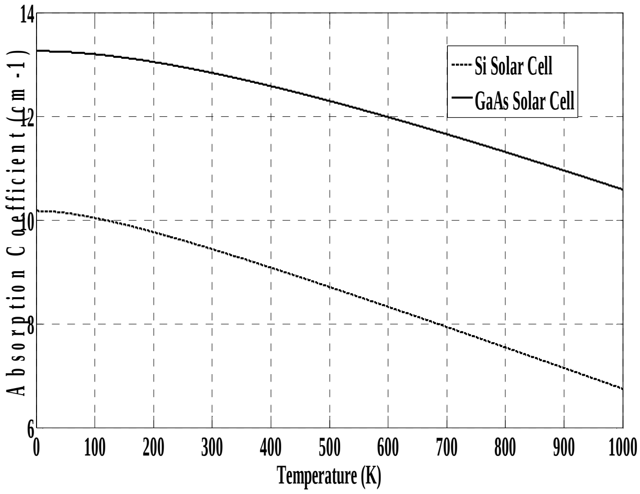

Fig. 1 Effect of temperature on absorption coefficient of solar cell. The solid line and the dashed line represent the absorption coefficient of the solar cell using GaAs and Si respectively.

Fig.1 represents the effect of temperature on the absorption coefficient of solar cell. The solid line represents the absorption coefficient characteristic of solar cell using GaAs based quantum dot in the active layer of the solar cell and the dashed line represents the absorption coefficient characteristics of the solar cell using Si quantum dot. The absorption coefficient of the solar cell decreases nonlinearly with the increase of temperature for both Si and GaAs based quantum dot as the active layer material of the solar cell. It is clear from the analytical results that the absorption coefficient of the solar cell using GaAs based quantum dot in the active layer is higher than that obtained using Si in the active layer of the solar cell. The higher absorption coefficient means that the ability of light absorption of solar cell has been increased significantly by using GaAs as the active layer material.

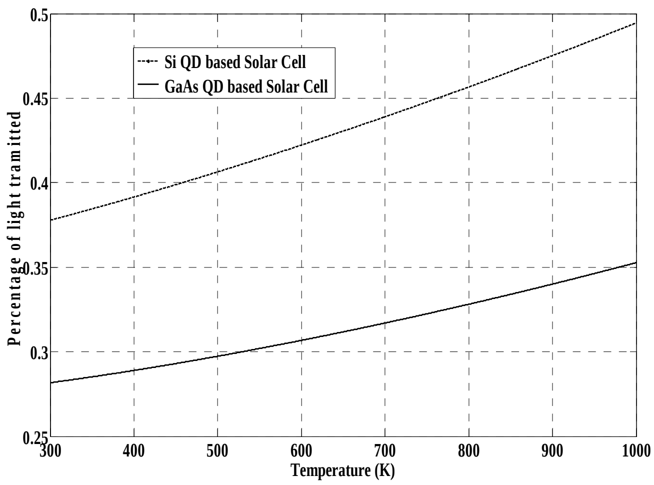

Fig. 2 Effect of temperature on the percentage of light transmitted through the solar cell. The solid line and the dashed line represent the percentage of light transmitted through quantum dot based solar cell using GaAs and Si respectively.

Fig.2 represents the effect of temperature on the percentage of light transmitted through the solar cell. The solid line represents the light transmission characteristic of solar cell using GaAs based quantum dot in the active layer of the solar cell and the dashed line represents the that of solar cell using Si quantum dot. The amount of light penetrated through the solar cell decreases nonlinearly with the increase of temperature for both Si and GaAs based quantum dot as the active layer material of the solar cell. It is ascertained from the analytical results that the absorption coefficient of the solar cell using GaAs based quantum dot in the active layer is higher than that obtained using Si in the active layer of the solar cell. The higher absorption coefficient means that the ability of light absorption of solar cell has been increased significantly by using GaAs as the active layer material.

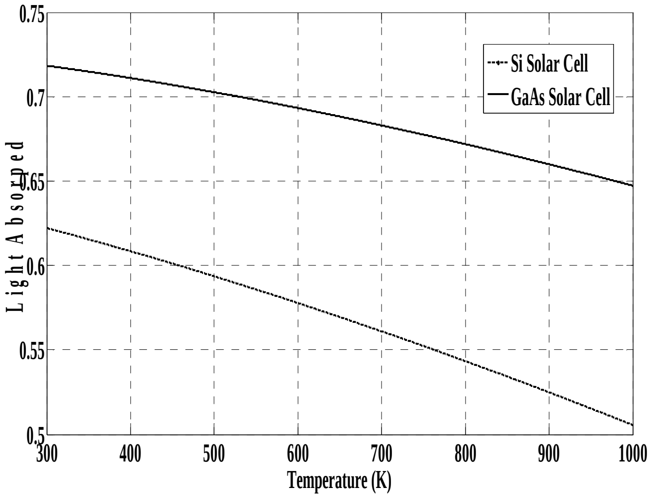

Fig. 3 Effect of temperature on the percentage of light absorbed by the solar cell. The solid line and the dashed line represent the percentage of light absorbed by the quantum dot based solar cell using GaAs and Si respectively.

Fig.3 represents the effect of temperature on the percentage of light absorbed by the solar cell. The solid line represents the light absorption characteristic of solar cell using GaAs based quantum dot in the active layer of the solar cell and the dashed line represents the that of solar cell using Si quantum dot. The amount of light absorbed by the solar cell decreases nonlinearly with the increase of temperature for both Si and GaAs based quantum dot as the active layer material of the solar cell. It is ascertained from the analytical results that the absorption coefficient of the solar cell using GaAs based quantum dot in the active layer is higher than that obtained using Si in the active layer of the solar cell. The higher absorption coefficient means that the ability of light absorption of solar cell has been increased significantly by using GaAs as the active layer material.

IV. CONCLUSION

In this paper we have focused mainly on the improvement of absorption phenomena of quantum dot based solar cell. We have studied extensively the temperature dependence of absorption coefficient, amount of light absorbed by the solar cell material and the amount of light transmitted through it using Si and GaAs based quantum dot in the active layer of the solar cell. The numerical results reveal that the absorption coefficient and the amount of absorbed light has been increased significantly by using GaAs based quantum dot in the active layer of the solar cell structure. Therefore GaAs based quantum dot will be a promising material to enhance the absorption of incident light on solar cell.

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