Antireflection Coating influences on the Quantum Efficiency and the Reflectivity of a GaAs / GaAS Solar Cell within the Visible Spectrum

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Abstract
A theoretical investigation of the change in reflectance of silicon carbide (SiC) as a function of the particle size was the main focus of the current research. In addition, a single layer of anti-reflection coating of a quarter the wavelength is designed and doped in gallium arsenide (GaAs/GaAs) solar cell. The efficiency of the cell is investigated in the range of (400-700 nm) using the Brus model and the theory of characteristic matrix in the case of vertical and 45° ray to the plane of the incidence. The max efficiency for the designed cell (Air/Nano SiC/(GaAs/GaAs) was (% 96.81) of the wavelength of 550 nm in the case of vertical incidence. While in the case of an incident ray of 45° to the plane of the incidence, the efficiency was (%92.99) for the perpendicular polarisation (S) and (%97.23) in the case of horizontal polarization (P). the thickness of the coating was (Ps=2.2 nm).

Keywords: quantity efficiency, solar cell, anti-reflection coating and SiC

Introduction

The new global has experience rapid and continuous developing in technology and its potential applications. However, the solar cells are low carbon energy source of the renewable to keep the increase of the atmospheric temperature below 2 °C [1, 2]. A solar cell is considered the best application on the solar energy which their operation principle depends on the photovoltaic effect[3, 4]. Increasing the efficiency of the solar cell was under high concerning by the researchers via adopting a variety of materials. Recently, the adopting the nanotechnology in the fabrication of the solar cells such as the incorporation of quantum dots (QDs) in solar cell manufacturing enhanced their efficiency in order to develop the physical and the structural properties of the solar cell materials[5-7]. However, reducing the loss in the quantum efficiency of the solar cell which is related to many factors, depended in the interaction between the light and the material of the cell. Where most semiconductors have
high reflectivity to the electromagnetic wave which can be reduced by the use of anti-
reflection coating [8]. The technique is depending on the phenomena of interference in the
thin films where the reflected wave experience changes in their optical path and phase.

Theoretical part

Quantitative efficiency

The quantitative efficiency (QE), which can be defined as a number of generated electron-
hole pairs by a photon, can be calculated from the following equation:

$$QE = (1 - R) \left[ 1 - e^{\alpha w} \right] \left( 1 + \frac{\alpha L_P}{1 + \alpha L_P} \right)$$  \hspace{1cm} (1)

Where $R$ is the reflectance coefficient, $\alpha$ is the absorption coefficient, $L_P$ the length of
diffusion in the region P for the minority of charges’ mobility and $w$ is the depletion region’s
width.

The diffusion length of the minority of charges’ mobility at region P can be determined[9]:

$$L_P = \sqrt{D_P \tau_P}$$  \hspace{1cm} (2)

$D_p$ and $\tau_p$ are the fixed deployment and relaxation time for region P, respectively.

The width of depletion region ($W$) can be calculated as below[10],

$$W = X_N + X_P = \sqrt{\frac{2K_s e_0}{q} \frac{N_A + N_D}{N_A \cdot N_D} V_{bi}}$$  \hspace{1cm} (3)

$X_N$ and $X_P$ are the width of the depletion at region N and P, respectively. $N_A$ and $N_D$ are the
negative and positive ion concentration, respectively. $e_0$, $K_s$, and $q$ are constants. While $V_{bi}$ is
the inward voltage.

Result and discussion
The reflectance as a function to the incident angle

The change in the reflectance of GaAs and SiC has been investigated as a function to the angle of the incident (0°-90°) and the external reflectance (n_i < n_sub), where the air is the media of the incident ray (see Fig 1.1 and Fig 1.2). In the case of vertical incidence (0° – 10°), it cannot be distinguished between the horizontal polarization mode (P) and the perpendicular polarization mode (S). The reflectance of the perpendicular polarization (R_S) increases with the increase in the angle of the incident in contrast to the values of the horizontal reflectance (R_P) which decrease and reach the minimum value at an angle called polarization angle or Brewster’s angle (θ_B). While, when the angle of incidence is higher than Brewster’s angle, the value of R_P and R_S increased to be 100%.

Fig 1. 1. Change in reflectance of GaAs as a function to the angle of incidence (0° – 10°).
The reflectance of GaAs and SiC as a function to the particle size

The reflectance of SiC has been investigated as a function to the particle size (Ps) which gives the quantum dots from the following equation $Ps = 2r_{ps}$ where $r_{ps}$ is the radius of the particle[11, 12]. The calculation of the reflectance is carried out at incident angles of ($\theta = 0^\circ$) and ($\theta = 45^\circ$). Most semiconductors have a similar optical behaviour when their particle size is lower than the bulk size. Furthermore, it is associated with an increase in their energy gap and a decrease of the refractive index. That change becomes very small where the radius of the particle $r_{ps}$ becomes equal or smaller than Bohr radius ($\alpha_e$) for the exciton. At that point, a dramatic change in the properties occurred with the decrease in the particle size because of the increase of the effect of quantum confinement. The decrease of the refractive index leads to a change in the value of the other optical properties. Table 1.1 shows the required properties used in the current study.
Table 1. Physical properties of the coating materials

| Bohr’s radius (nm) | Hole effective mass \( m_h^* \) | Electron effective mass \( m_e^* \) | Energy gap \( E_g^{bulk} \) (eV) | Refractive Index | Material |
|-------------------|-------------------------------|-------------------------------|-------------------------|----------------|-----------|
| 2.7               | 0.6                           | 0.68                          | 2.36                    | 2.58           | 3C-SiC    |

Fig 1.3. The reflectance change of SiC with the particle size in the case of vertical incidence.

Fig 1.4. The reflectance change of SiC with the particle size at the incidence angle of 45°.
Fig 1.5. The change in the refractive index and the energy gap of SiC with the particle size

The designed SiC-nano-coating on GaAs/GaAs solar cell

The quantum efficiency for a solar cell is calculated before coating. The quantitative efficiency was $\text{QE} = 69.63\%$ and the absorption coefficient was $\alpha = 6.8 \times 10^4 \text{ cm}^{-1}$. While the width of the depletion area $w = 0.094 \times 10^4 \text{ cm}$. In addition, the reflective $R = 30.2\%$ and the length of the load bearers ($L_p = 3.6 \times 10^{-4} \text{ CM}$). Fig 1.6 and Fig 1.7 demonstrate the reflectance and the quantum efficiency for a single layer of SiC which has a thickness ($L = 0.25 \lambda_0$) coated on GaAs/GaAs solar cell surface at an incident wavelength ($\lambda_0 = 550 \text{ nm}$). It has been noticed that the reflectance becomes ($R \approx 11\%$) when the particle size of the coating is ($P_s = 40-12 \text{ nm}$). While it decreased due to the effect of the quantum confinement and the highest quantum efficiency obtained when the particle size ($P_s = 2.2 \text{ nm}$).
Fig 1. 6. The change in the reflective of the (Air/ Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size in the case of the vertical incidence, at the wavelength of (λ₀ = 550 nm) and (L = 0.25 λ₀).

Fig 1. 7. The quantum efficiency of (Air/ Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size in the case of the vertical incidence, at the wavelength of (λ₀ = 550 nm) and (L = 0.25 λ₀).

It has been observed that the designated (Air/ Nano SiC /(GaAs/GaAs) achieved the lowest value of the reflectance (R=0.74%) in the case of vertical incidence at the designated wavelength. In addition, the highest quantum efficiency for the coating was 96.81% at a particle size of 2.2 nm which can be suggested as a proper particle size for that designated coating.
Fig 1.8 to Fig 1.11 present the influence of the angle of incidence (0°, 45°) into the value of the reflectance and the quantum efficiency in the wavelength range between 400-700 for the designated anti-reflective coating. At the incident angle of \( \theta_o = 0^\circ \), the polarization of the reflectance wave is quite low, and it is difficult to differentiate between the polarization modes (P, S). While at \( \theta_o = 45^\circ \), because of the difference in the optical permeability, it can be differentiated between the polarization modes. Table 1.2 illustrates the effect of the angle of incidence into the refractivity.

### Table 1.2 The change in reflectivity with the angle of incidence of (Air/Nano SiC/(GaAs/GaAs)) at (Ps = 2.2nm).

| Angle of incidence (\( \theta^\circ \)) | Reflectivity (R\%) of polarization mode at (\( \lambda_o=550 \text{ nm} \)) | Quantity efficiency (QE\%) of polarization mode at (\( \lambda_o=550 \text{ nm} \)) |
|--------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
|                                      | \( S \) 0.74                                                                                      | 0.74                                                                 | 96.81                                                                 | 96.81                                                                 |
|                                      | \( P \) 0.74                                                                                      | 0.74                                                                 | 96.81                                                                 | 96.81                                                                 |
| 45                                   | 4.65                                                                                             | 0.31                                                                 | 92.99                                                                 | 97.23                                                                 |

Fig 1.8. The change in the reflective of the (Air/Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size when the angle of incidence \( \theta_o = 0^\circ \).
Fig 1. 9. The quantum efficiency of (Air/Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size when the angle of incidence $\theta_o = 0^\circ$.

Fig 1. 10. The change in the reflective of the (Air/ Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size when the angle of incidence $\theta_o = 45^\circ$.

Fig 1. 11. The quantum efficiency of (Air/ Nano SiC/(GaAs/GaAs) designed anti-coating with the particle size when the angle of incidence $\theta_o = 45^\circ$. 
Conclusion

The quantum efficiency of the solar cell is related to the reflectance of the surface of the incidence to the electromagnetic waves. The maximum quantum efficiency of the designated (Air/Nano SiC/(GaAs/GaAs) solar cell was 96.81% at the wavelength of ($\lambda_0 = 550$ nm) in the case of vertical incidence. While in the case of incidence at the angle of 45°, the efficiency was 92.99% at the perpendicular polarization (S) and 97.23% at the horizontal polarization when the particle size is 2.2 nm.

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