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Efficiency Enhancement of GaAs Solar Cell using Si3N4 Anti-reflection Coating

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ABSTRACT

The objective of this work is to improve the conversion efficiency of the single junction GaAs solar cell by reduce the front surface reflectivity .For the first time Si_3N_4 will be used as an ARC with GaAs substrate. Compared with MgO, silicon nitride has the properties of low density, high temperature strength, high fracture toughness and high hardness. The thickness of silicon nitride film was optimized for minimum reflectivity, the results show that the efficiency of GaAs solar cell with ARC is increased to 27.16 % at emitter doping and base doping equal $1x10^{15}$, emitter thickness and base thickness equal 0.4um and 2um, respectively and Si_3N_4 ARC thickness equals 75 nm. Also it has been realized that by using saw tooth in the surface layer of the solar cell structure and optimizing its textured angle and depth, the efficiency will be increased to 29.57 %. The simulation that has been utilized in this work is PC1D.

1. Introduction

A solar cell made of GaAs semiconductor presents a higher performance in comparison with silicon semiconductor. The GaAs band gap is 1.43 eV, it is a direct band gap material, which means that it can be used to absorb and emit light efficiently, and it is nearly ideal for single junction solar cells. GaAs has so high absorptivity that it requires a cell of only a few microns thick to absorb sunlight. Moreover, GaAs cells are relatively insensitive to heat and very resistant to radiation damage. This, along with its high efficiency, makes GaAs very desirable for space applications. One of the greatest advantages of gallium arsenide PV cell materials is the wide range of design options possible. A cell with a GaAs base can have several layers of slightly different compositions that allow a cell designer to precisely control the generation and collection of electrons and holes [1].

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A main challenge for the performance improvement of solar cells is the reflection losses. An ideal solar cell should absorb all useful photons to generate electrical charge. The more photons absorbed, the more efficiency obtained.

Different methods have been used to reduce the reflectance of solar cells. Light trapping and Anti Reflection Coating (ARC) are amongst the widely applied methods to increase the solar cells efficiency [2].

Anti-reflection coatings on solar cells consist of a thin layer of dielectric material, with a specially chosen thickness so that interference effects in the coating cause the wave reflected from the anti-reflection coating top surface to be out of phase with the wave reflected from the semiconductor surfaces.

The material Si_3N_4 is an electrical insulator and is not wet by nonferrous alloys. Silicon nitride is a rather expensive material, but its performance to cost benefit ratio is excellent in the applications where it can outperform the normally utilized materials with long life and very reliable low maintenance operation. The properties of silicon nitride are low density, high temperature strength, high fracture toughness and high hardness [3].

In this work, Si_3N_4 has been used as an ARC on GaAs and with the help of PC1D simulation tool [5] we optimize the thickness of AR-Coating. In addition, the effects of thickness and doping of the base and emitter of GaAs have been studied. Moreover, we proposed texturing to the front surface with a specific angle and depth to enhance the efficiency.

In section 2, the proposed structure of GaAs solar cell with ARC is presented. The simulation results and conclusion will be presented in section 3 and section 4, respectively.

2. Structure

We choose a simple homo-junction structure of photovoltaic solar cell. The parameters used in GaAs homo-junction solar cell simulation are the device area 100 cm2, thickness of p-region and n- region 300 nm, bulk recombination 1000 µs, doping 1×10^{18} cm⁻3, ohmic contacts of resistance 20 Ω, wavelength range 300 to 1200 nm.

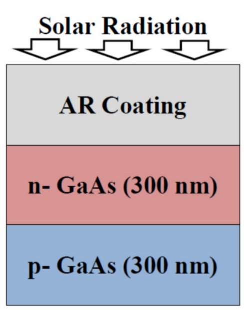

Fig. 1. Homo-junction solar cell structure with AR coating

3. Results and Discussion

In this section a single junction GaAs solar cell without and with a single Silicon Nitride ARC layer has been designed and simulated. Moreover, the performance of the cell is evaluated for the single layer ARC with various thicknesses. The current and power density of the GaAs solar cell without ARC is presented in Fig. 2. It is evident that, the maximum power density is 14.89 mW/cm^2, open circuit voltage is 1.091 V, and short circuit current density is 15.37 mA/cm^2.

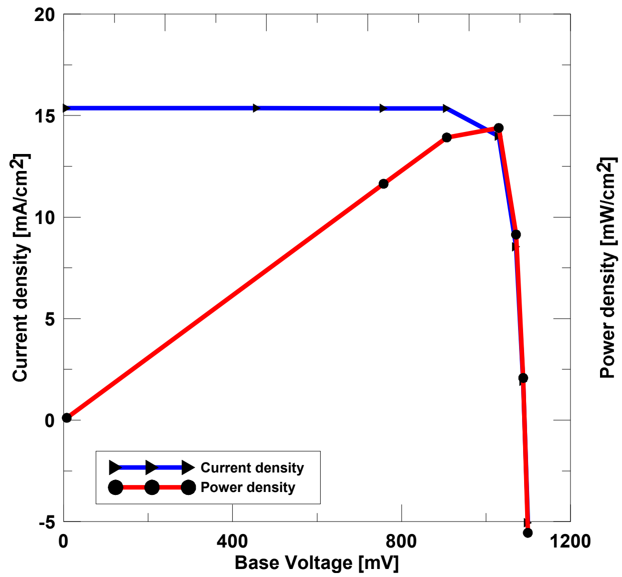

Fig. 2. Current density and Power density versus base voltage curve of solar cell without ARC

From these results the fill factor and the efficiency can be calculated using equations 1 and 2 respectively [10]

$$FF = \frac{Vm\ Im}{Voc\ Isc} \tag{1}$$

$$\eta = \frac{Pm}{Pin} = \frac{Voc * Isc * FF}{Pin} * 100\% \tag{2}$$

The emitter and base layer thickness have a dramatically effects on the solar cell efficiency. Figure 3 depicts the effect of emitter layer thickness, tE, on the solar efficiency for different values of base layer thickness. It is evident that, the maximum efficiency of the GaAs without ARC is 17.46 % and it will be occurred at emitter and base thicknesses of 0.4 µm and 2 µm, respectively. As expected, the solar efficiency is very sensitive to the emitter layer thickness. The solar efficiency will be decreased from 16.5 % to 7.5 % when the emitter thickness increased from 1µm to 5 µm. It is also clear that once the emitter thickness is higher than 1.5 µm, the solar efficiency will be decreased with the same slope regardless of the value of base thickness.

Increasing the doping in the emitter layer will enhance the built-in electric field which leads to a higher V_{oc} and lower resistance, but higher levels of doping result in damage to the crystal. Figure 4 and Figure 5 shows the effects of emitter and base doping on the solar efficiency. The doping concentration of the emitter and base layers is varied from 10^{15} cm^{-3} to 10^{20} cm^{-3}. As expected, the efficiency drops at very high emitter and base doping because the growing of recombination rate. Moreover, the effect of ARC material such as Si_3N_4 and MgO on the solar efficiency is presented in Fig. 4 and Fig. 5. It is evident that the Si_3N_4 ARC material presents a higher efficiency over all the doping range. The maximum efficiency achieved while the Si3N4 ARC is used and the emitter and base doping concentration are 10^{17} cm^{-3}.

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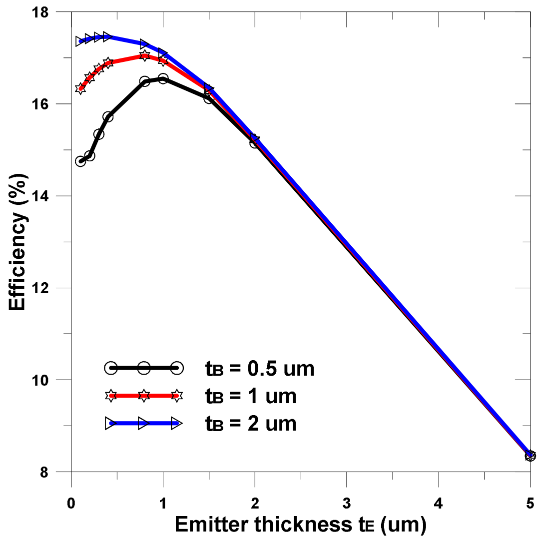

Fig. 3. Efficiency versus Emitter thickness at various base thicknesses with $N_D = N_A = 10^{15}$ cm^{-3}

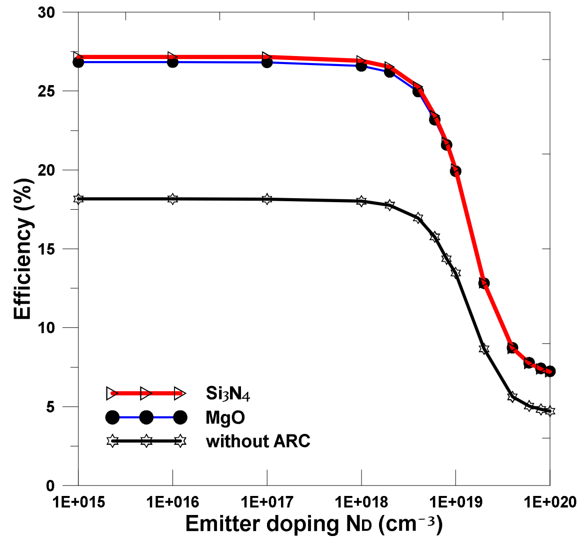

Fig. 4. Efficiency versus Emitter doping with and without ARC at $N_A = 10^{15}$ cm-3, t_E = 0.4 µm, and t_B= 2µm

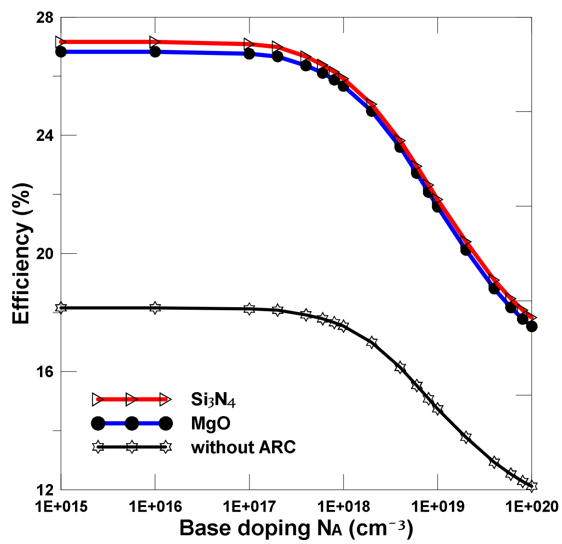

Fig. 5. Effect of base doping on the solar efficiency with and without ARC at ND= 10^{15} cm^{-3}, tE = 0.4 µm, and tB= 2µm

Indeed, the ARC thickness has a drastically effects on the solar efficiency. In Fig. 6, we study the effect of Si3N4 and MgO ARC thickness on the efficiency. It is clear that, For Si3N4 and MgO ARC, the efficiency will be increased with the thickness then it will drop at a 75 nm and 90 nm, respectively.

So for the further simulation, Si3N4 ARC on a GaAs substrate will be used. The emitter and base doping level of 10^{17} cm^{-3} are considered. Moreover, we use the emitter and base thickness of 0.4 µm and 2 µm respectively. In Fig. 7, the J-V characteristic of the proposed solar cell is presented. The simulation results show that the maximum efficiency can be achieved is 27.16 %, the open circuit voltage is 1.1 V and the short circuit current density is 27.52 mA/cm².

Surface texturing, either in combination with an anti-reflection coating or not, can also be used to minimize reflection. Any "roughening" of the surface reduces reflection by increasing the chances of reflected light bouncing back onto the surface, rather than out to the surrounding air. So, the front surface is textured to increase the amount of light coupled into the cell. To enhance the efficiency, texturing can be made to the front surface of Si_3N_4 with certain depth and angle. Figure 8 represent the effect of angle of texturing on the solar efficiency. It has been found that the efficiency is increased exponentially with the angle of texturing then it will drop dramatically. We achieved an efficiency of 29.57 % by using angle of texturing equals 103.16̊ with depth 0.4 µm.

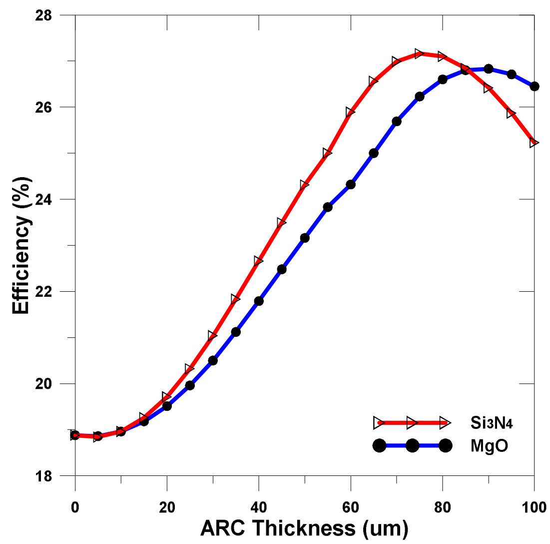

Fig. 6. GaAs solar efficiency for various ARC thicknesses with ND = NA= 10^{15} cm^{-3}, tE = 0.4 µm, and tB= 2µm

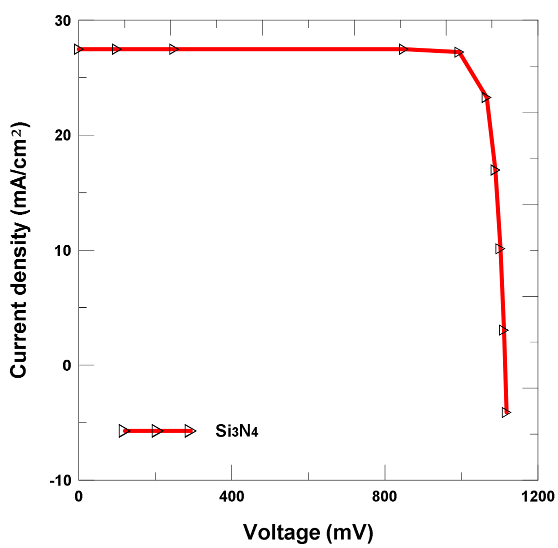

Fig. 7. JV characteristics for GaAs solar cell with Si_3N_4 ARC layer

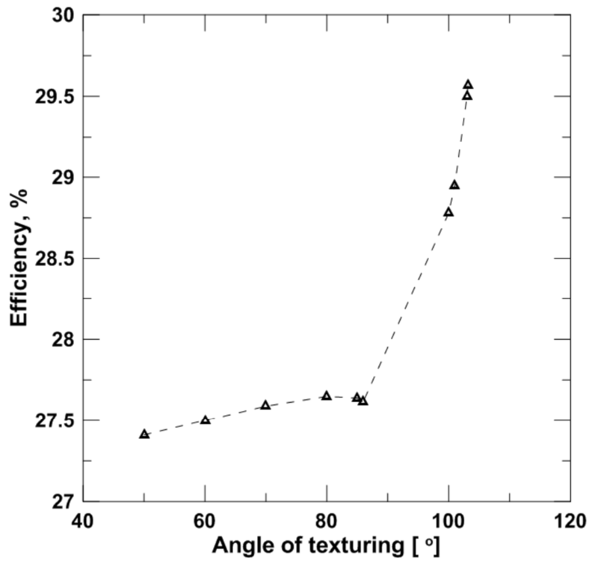

Fig. 8. Efficiency versus Angle of texturing

4. Conclusion

The application of AR-coating on the front surface of the GaAs solar cell, gives us very encouraging results. The current density is increased from 15.37 mA/cm² to 27.48 mA/cm² at 75 nm thicknesses for ARC Si_3N_4 film and to 29.55 mA/cm2 after adding surface texturing. The efficiency is increased from 14.89 % to 27.16 % for Si_3N_4 ARC and to 29.57 % after making texturing to the front ARC surface.

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