World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:9, No:1, 2015

The Effect of Global Solar Variations on the Performance of n-AlGaAs/p-GaAs Solar Cells

A. Guechi, M. Chegaar

Abstract**—**This study investigates how AlGaAs/GaAs thin film solar cells perform under varying global solar spectrum due to the changes of environmental parameters such as the air mass and the atmospheric turbidity. The solar irradiance striking the solar cell is simulated using the spectral irradiance model SMARTS2 (Simple Model of the Atmospheric Radiative Transfer of Sunshine) for clear skies on the site of Setif (Algeria). The results show a reduction in the short circuit current due to increasing atmospheric turbidity, it is 63.09% under global radiation. However increasing air mass leads to a reduction in the short circuit current of 81.73%. The efficiency decreases with increasing atmospheric turbidity and air mass.

Keywords**—**AlGaAs/GaAs, Solar Cells, Environmental parameters, Spectral Variation, SMARTS.

I. Introduction

CRYSTALLINE silicon solar cells have excellent efficiencies, however, according to data presented by the authors on material fluxes and energy consumption there are serious bottlenecks for this technique with respect to future large scale applications both from an economical as well as from an ecological point of view.

The band gap of silicon at about 1.1 eV and its indirect band gap nature, however, result in solar cells with low conversion efficiency [1], [2]. On the contrary, Gallium Arsenide (GaAs) is generally the material of choice when choosing a single material system for a space solar cell design. This is because GaAs has optimal bandgap energy for conversion of the solar flux into electrical power [3].

This compound semiconductor could be used to form hetero-structures for example, using lattice-matched GaAlAs and GaAs [4]. In the heterostructure, the wider bandgap GaAlAs is also functioning as an optical window of the solar cells. It is well known that in photovoltaic applications, AlGaAs/GaAs heterostructure solar cells yield high efficiency, which results from a wide gap optical window of AlGaAs and a high absorbing effect of GaAs due to its direct band gap property at 1.4 eV [5]. Multi junction solar cells have been shown to make the most efficient use of the solar spectrum [6].

There has been an upsurge of interest in developing GalnP/GaAs solar cells for space and terrestrial applications because of their high conversion efficiency. Triple junction solar cells (3JSC) consisting of lattice matched InGaP (1.9eV) / GaAs (1.43eV) / Ge(0.67eV) with conversion efficiencies of 32% [7]. Thus, the large band gap of GaP makes it a good candidate for the top junction solar cell [8], [9].

The aim of this study is to evaluate the effect of changes in spectral distribution of global irradiation due to the variation of atmospheric parameters such as air mass and turbidity on the performance of (n- AlGaAs/p-GaAs) solar cells. The global solar irradiance striking a (n- AlGaAs/p-GaAs) solar cell is estimated using the spectral irradiance model for clear skies SMRTS2. The variation of the common performance namely short circuit current, fill factor, open circuit voltage, and efficiency are shown and discussed.

II. Calculation Procedure

A. The SMARTS Model

Accurate predictions of incident solar radiation are necessary in many different disciplines, not just solar energy applications. Even though it is relatively easy to evaluate irradiances with appropriate broadband radiation models, spectral models provide considerably more flexibility, and normally better accuracy because of the more physical nature of their modeling. In many spectrum-dependent applications, they even are the only resource. A number of spectral radiative models have been described or used in the literature, and some of them are reviewed elsewhere [10]-[12].

The SMARTS2 (Simple Model of Atmospheric Radiative Transfer of Sunshine) model was developed by Gueymard [13]-[15] is based upon an extensive revision of the algorithms used to calculate direct, diffuse and global radiation [16], [17] and consists of a separate parameterization of the different extinction processes involved in the atmosphere. In this model, more accurate transmittance functions for all atmospheric extinction processes are introduced as well as temperature and humidity effects. SMARTS2 is used to generate the global component solar spectra for the site of Setif (Algeria) (36.18°N, 5.41°E and 1081m).

B. Cell Parameters Calculation

The short circuit current density Jsc of a device is directly related to the irradiation can be calculated as:

$$J_{sc} = \int E(\lambda)\, SR(\lambda)\, d\lambda \tag{1}$$

where E (λ) is the energy of the incident light and SR (λ) is the spectral response at the given wavelength. This implies a linear relationship with irradiation. The temperature variation

A. Guechi is with the Institute of Optics and Precision Mechanics, laboratory of Optoelectronics and Components, Setif-1 University, 19000 Setif, Algeria (phone: (213)36837418; e-mail: ab_guechi@ yahoo.fr).

M. Chegaar is with the Physics Department, laboratory of Optoelectronics and Components, Setif-1 University, 19000 Setif, Algeria (e-mail: chegaar@yahoo.fr).

is device and technology dependent, mainly on the magnitude of the band gap and the device specific spectral response.

FF is the fill factor and is determined as [18]:

$$FF = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \quad (2)$$

where

$$v_{oc} = \frac{V_{oc}}{n\left(\frac{kT}{q}\right)} \quad (3)$$

The open circuit voltage is calculated using:

$$V_{oc} = n\frac{kT}{q}\ln\left(\frac{I_{ph}}{I_s} + 1\right) \quad (4)$$

The ideality factor *n*, and the saturation current, *Is*, are computed from the *I-V* characteristics using the modified analytical five-point method [19]. The fill factor and the conversion efficiency of the solar cell are linked through:

$$\eta = FF\frac{V_{oc} I_{sc}}{P_i S} \quad (5)$$

where *Isc* is the short circuit current, *S* is the solar cell area, and *Pi* is the total irradiance in W/m^2 and is given by:

$$P_i = \int_0^\infty E(\lambda)\, d\lambda \quad (6)$$

with *E (λ)* is the spectral irradiance. The *Isc*, *Voc* and *FF* all depend on the irradiance, incident spectrum and stabilized state. The short-circuit current is mainly affected by the spectrum.

Fig. 1 shows the measured spectral response of the n-AlGaAs/p-GaAs solar cells considered in this work.

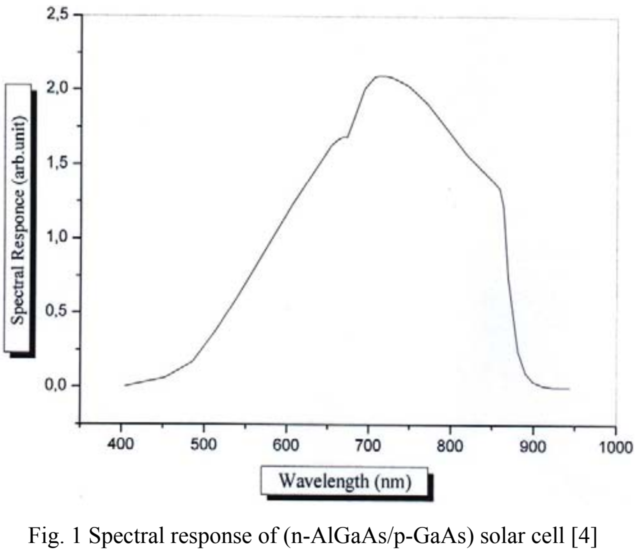

Fig. 1 Spectral response of (n-AlGaAs/p-GaAs) solar cell [4]

III. Results and Discussion

A. Air Mass Effect

The amount of atmosphere (air thickness) traversed by a sunray as it travels from the top of the atmosphere to a point on the Earth's surface is often called the air mass. The longer the path through the atmosphere, the greater the air mass encountered by the sunray, and the greater the attenuation. Since there are no gases or aerosols in space between the Sun and the top of the Earth's atmosphere, the air mass at the top of the atmosphere is zero (AM0). When the sun angle is 90°, the air mass from the top of the atmosphere is defined as having a value of one (AM1). The air mass along any path from the top of the atmosphere to the Earth's surface is approximately related to the sun angle.

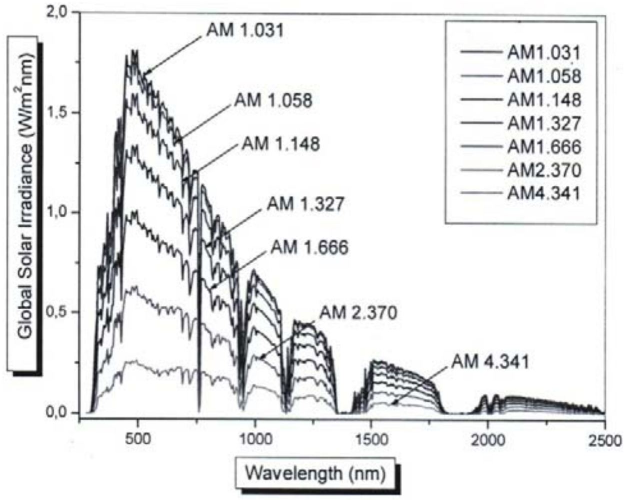

Fig. 2 Global solar irradiance as function of wavelength for different values of air mass at Setif

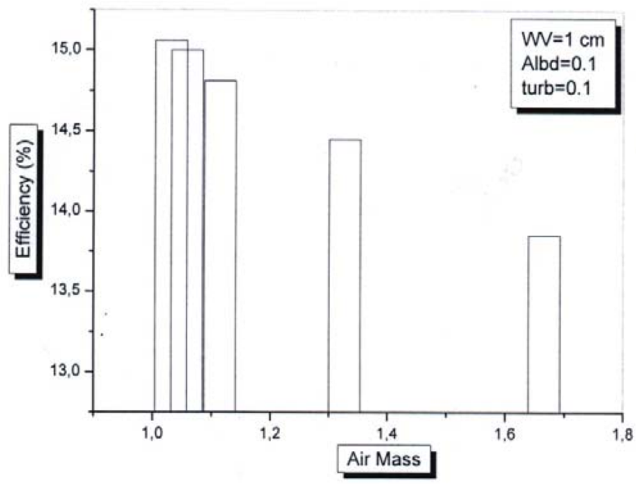

Fig. 3 Efficiency as function of air mass under global irradiance

The global spectral irradiance as a function of wavelength for different values of air mass at Setif (36.18°N, 5.41°E and 1081m) is shown in Fig. 2. In this figure an increase in air mass reduces global solar irradiance. The short circuit current decreases with increasing air mass, this reduction is 81.73% when the air mass increases from AM= 1.031 to AM = 4.341. The efficiency decreases with increasing air mass. This is illustrated in Fig. 3.

B. Turbidity Effect

Atmospheric turbidity is an important parameter for assessing the air pollution in local areas, as well as being the main parameter controlling the attenuation of solar radiation reaching the Earth's surface under cloudless sky conditions. Atmospheric turbidity is a measure of the opacity of the atmosphere, and is defined as the effect of aerosols, through their total optical depth, in reducing the transmission of direct solar radiation to the surface below that through a purely molecular atmosphere. Turbidity affects longer wavelengths using more than Rayleigh scattering, it is used to quantify the attenuation by aerosols that is responsible for increasing diffuse solar radiation as well as responsible for changing the spectral composition Fig. 4 shows the global spectral irradiance as a function of wavelength for different values of turbidity at Setif. Increasing turbidity decreases the global solar spectrum at wavelengths with high photon energy. Naturally greater turbidity results in higher amount of global radiation.

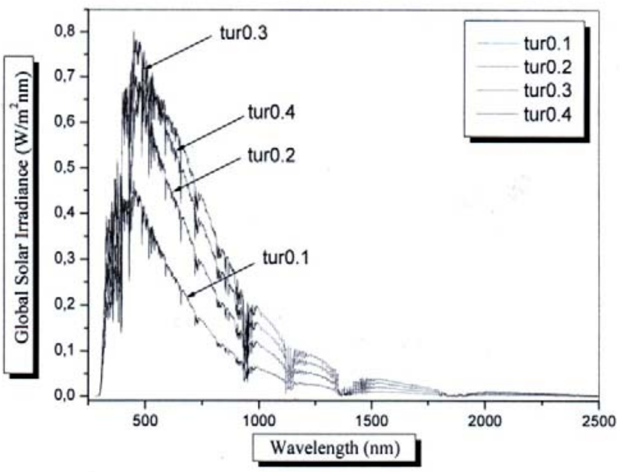

Fig. 4 Global solar irradiance as function of wavelength for different values of Turbidity at Setif

Fig. 5 shows the influence of the atmospheric turbidity on the efficiency of the solar cell under global solar irradiance. The efficiency decreases with increasing turbidity, so that the output current is decreased. The increase in the short circuit current due to increasing turbidity is 63.09% when the turbidity increases from 0.1 to 0.40.

The variation of the short current, open circuit voltage, fill factor and efficiency as function of the air mass and turbidity are illustrated in Table I.

IV. Conclusion

The purpose of this work was to know how (n- AlGaAs/p-GaAs) solar cells perform under possible global solar spectrum variations due to the variation of the air mass, and turbidity using the spectral irradiance model SMARTS2 (Simple Model of the Atmospheric Radiative Transfer of Sunshine) for clear skies on the site of Setif (Algeria). The results show that the short circuit current decreases with increasing turbidity and air mass. The efficiency decreases with increasing air mass and turbidity. From this analysis, we conclude that the air mass and the turbidity have a significant influence on the overall performance of the examined solar cells.

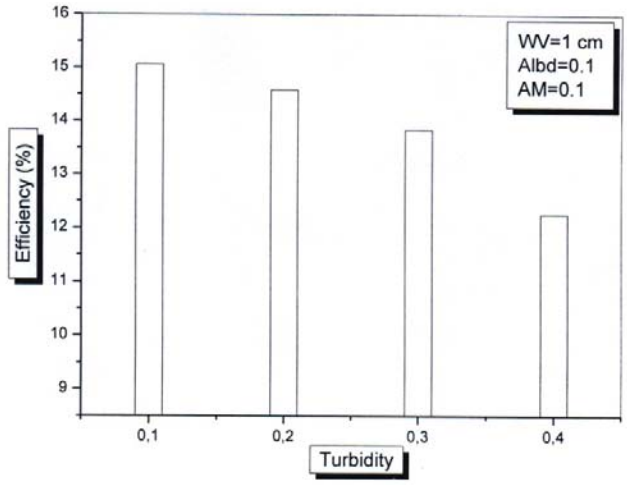

Fig. 5 Efficiency as function of turbidity under global irradiance

TABLE I
Effect of Atmospheric Parameters on AlGaAs/GaAs Solar Cells Performance

Environmental	Parameters	Jsc (mA/cm²)	Voc (V)	FF
Turbidity	0.1	33.1430	0.7534	0.6907
	0.2	31.0161	0.7483	0.6894
	0.3	27.9386	0.7403	0.6873
	0.4	23.0008	0.7255	0.6833
Air Mass	1.031	33.1430	0.7534	0.6907
	1.058	32.2103	0.7512	0.6902
	1.148	29.4460	0.7443	0.6884
	1.327	25.0267	0.7319	0.6851

References

[1] C. Becker et al., "Polycrystalline silicon thin-film solar cells: Status and perspectives", Solar Energy Materials and Solar Cells, vol. 119, 2013, pp. 112–123.

[2] N. S. Zin, A. Blakers, E. Franklin, V. Everett, " Design, characterization and fabrication of silicon solar cells for ≫50% efficient 6-junction tandem solar cells", Photovoltaic Specialists Conference, PVSC '08, 2008, 33rd IEEE, pp. 1–4.

[3] T. Sojoudi et al., "Comparing AlGaAs-GaAs Heterojunction Materials with CdS-InP Anisotype for Solar Cells Efficiency in Concentrator Systems", Research Journal of Applied Sciences, Engineering and Technology, vol. 6, 2013, pp. 1923-1927.

[4] S. Thainoi et al, "n-GaAlAs on p-GaAs heterostructure solar cells grown by molecular beam epitaxy ", Solar Energy Materials & Solar Cells, vol. 90, 2008, pp. 2989–2994.

[5] I. Garcia, I Rey-Stolle and C. Algora, "Performance analysis of AlGaAs/GaAs tunnel junctions for ultra-high concentration photovoltaics", J. Phys. D: Appl. Phys, vol. 45, 2012, pp.101-109.

[6] K. Geoffrey , C. Bradshaw et all., "Carrier Transport and Improved Collection in Thin-Barrier InGaAs/GaAsP Strained Quantum Well Solar Cells", IEEE Journal of Photovoltaic's, vol. 3, 2013,pp. 278 - 283

[7] R. R. King, A. Boca,W. Hong, X.-Q. Liu, D. Bhusari, D. Larrabee, K. M. Edmondson, D. C. Law, C. M. Fetzer, S. Mesropian, and N. H. Karam, "Band-gap engineered architectures for high-efficiency

multijunction concentrator solar cells", 24th Eur. Photovoltaic Sol. Energy Conf. Exhib., Hamburg, Germany, 2009.

[8] X. Lu et al. "Improving GaP Solar Cell Performance by Passivating the Surface Using AlxGa1–xP Epi-Layer", IEEE Journal of the Electron Devices Society, vol.1, 2013,pp. 111-116

[9] M. Sojoudi, R. Madatov, T. Sojoudi , "optimization of efficiency of solar cells by accelerated electron ray to have an optimal and constant energy", International Journal on Technical and Physical Problems of Engineering (IJTPE), vol.3, 2011,pp.68-71.

[10] C .Gueymard, "Temporal variability in direct and global irradiance at various time scales as affected by aerosols", Solar Energy, vol. 86, 2012, pp. 3544–3553.

[11] V. Badescu C. Gueymard, "Computing global and diffuse solar hourly irradiation on clear sky. Review and testing of 54 models", Renewable and Sustainable Energy Reviews, vol. 16, 2012, pp. 1636–1656.

[12] C. Gueymard, "REST2: High-performance solar radiation model for cloudless-sky irradiance, illuminance, and photosynthetically active radiation –Validation with a benchmark dataset ". Solar Energy, vol. 82, 2008, pp. 272–285.

[13] C. Gueymard, R. George, "Gridded aerosol optical depth climatological datasets over continents for solar radiation modeling". Proceedings of the Solar World Congress. International Solar Energy Society, Orlando, FL, 2005.

[14] C.Gueymard, "SMARTS2, Simple Model of the atmospheric Radiative Transfer of Sunshine: Algorithms and performance assessment". Report. FSEC-PF-270-95, Florida-Solar Energy Center, Cocoa, FL, 1995

[15] C. Gueymard, "Visibility, aerosol conditions, and irradiance attenuation close to the ground Comments on Solar radiation attenuation in solar power plants by J. Ballestrin and A. Marzo", Solar Energy, vol. 86, 2012, pp. 1667-1668.

[16] C .Gueymard, D. R. Myers "Evaluation of conventional and high-performance routine solar radiation measurements for improved solar resource, climatological trends, and radiative modeling", Solar Energy , 2009, vol. 83, pp. 171–185.

[17] M. Kocifaj, C. Gueymard, "Theoretical evaluation of errors in aerosol optical depth retrievals from ground-based direct-sun measurements due to circumsolar and related effects", Atmospheric Environment, vol. 45, 2011, pp. 1050–1058.

[18] M. A Green, "Solar Cells, Operating Principals, Technology, and System Applications", Prentice-Hall Inc., Englewood Cliffs, 1982.

[19] M. Chegaar, G. Azzouzi, and P. Mialhe, "Simple parameter extraction method for illuminated solar cells". Solid-State Electronics, vol. 50, 2006, pp. 1234 -1237.