Analysis of Solar Cell with Mgo-Zno Anti-Reflective Coating

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Abstract— In general solar PV panels are used without any anti-reflective coating. Its efficiency is only about 6-7%. Surface passivation plays a significant role in upgrading solar cell performance. When the anti reflection coating is used on solar cell, the efficiency gets increased for a specified thickness of coating. In this study the combination of MgO-ZnO material is used as an anti- reflective coating on silicon solar cell. The thickness of the coating is optimized 86nm and 75nm for p-type single crystalline silicon solar PV cell, considering the optical response in the 400nm to 800nm wavelength range. Theoretical model has been developed to determine the refractive index and other related optical properties such as transmissivity, reflectivity for the solar PV panel without the anti-reflective Coating. The combination of MgO-ZnO material showed higher refractive index value. This is investigated theoretically and compare the optical properties of solar cell with coating and without coating.

Key words: P-type single crystalline solar cell, anti-reflective coating, refractive index, reflectivity, transmissivity

I. Introduction

The sun is the largest member of the solar system with other members revolving around it. It is a sphere of intensely hot gases with a diameter of 1.39 x 10^9 m and on an average distance of 1.5 x 10^{11} m from the earth. The solar energy in the form of light and heat from the sun forms the base of sustenance of all living beings in the earth. It is an intermittent, eco-friendly and non-polluting energy, freely available throughout the world. Humans rely on solar energy to survive, including all other forms of renewable energy (except for geothermal resources) Although the total amount of solar energy resources is ten thousand times of the energy used by humans, but the solar energy density is low, and it is influenced by location, season, which is a major problem of development and utilization of solar energy.

The two major methods of harnessing solar energy are solar thermal energy conversion and solar photovoltaic method. Solar photovoltaic method is the direct conversion of light energy into electric power. solar photovoltaic generation is effected by the use of solar PV modules which consist of array of solar cells. the conversion efficiency of the solar cell is generally 16-20%.the conversion efficiency is and affected by the type of PV module and ambient conditions. Thus the maximum solar radiation is dissipated as heat in the solar PV module.

The most widely used solar PV module is single crystalline silicon PV module. The surface of the silicon wafer contains sling wing bonds and other defects. These defects include recombination of the electron hole pairs generated in the PV module. These defect is termed as surface recombination. This surface recombination defect is reduced by surface passivation mechanism. The surface passivation technique enhances the open circuit voltage and fill factor. Reduction of electron hole recombination at the semiconductor surface is effected by field-effect passivation. [9]

The electron hole concentration at the surface can be altered by guarding of the charge carriers by maintaining the internal electric field. Surface passivation is the efficacious method for achieving this, thereby enhancing the solar cell efficiency. [9]

In photovoltaic industry, anti-reflection coatings mostly used are metal oxides such as SiO_2, TiO_2, ZrO_2. In a single crystalline silicon solar cell, ZnO was coated by atomic layer deposition method with different thickness range of 600nm – 1000nm. By this anti-reflection coating material the conversion efficiency enhances by 6%.[5]

In a multi crystalline silicon solar cell, SiO_2 was coated by surface passivation technique method to enhance the open circuit voltage and short circuit current with a thickness range of 850nm – 1100nm. By this SiO_2 coating material the coversion efficiency enhances by 0.3%.[8] [9]

Combination of two materials as anti-reflection coatings were also been tried by the researches to improve the conversion efficiency. Such combinations used by researches were Al doped ZnO, ITO[1], TiO_2 - SiO_2[3]. Thus in this work combination of MgO – ZnO as a anti-reflection coating to enhance the optical properties of solar cell.

II. Theoretical Modelling

The equations defined below for theoretical modeling of silicon solar cell anti reflective coating are considered as in Sukhatme S P, et.al.[7]

A. Incident Angle And Incident Total Solar Radiation Falling On The Surface:

Declination angle can be determined by using the following relation[7],

$$\delta \text{ (in degrees)} = 23.45 \sin\left(\frac{360}{365}(284 + n)\right)$$

For horizontal surface incident angle can be calculated using the following formula,[7]

$$\text{Cos}\theta = \text{Cos}\,\theta z = \sin\ \sin\ + \text{Cos Cos Cos}$$

$$\text{Global radiation } Ig = Ib + Id$$

B. Efficiency Of A Silicon Solar Cell Without Anti Reflection Coating:

Efficiency is calculated from the short circuit current and open circuit current, [7]

$$\frac{I_{sc}}{I_o} = \exp\left(\frac{eV_{oc}}{KT}\right) - 1$$

Maximum voltage that can produced by the solar cell using the following expression [7],

$$\left(1 + \frac{eV_m}{KT}\right)\exp\left(\frac{eV_m}{KT}\right) = 1 + \frac{I_{sc}}{I_o}$$

Maximum current that can produced by the solar cell using the following expression[7],

$$I_m = \frac{\left(\frac{eV_m}{KT}\right)}{\left(1+\frac{eV_m}{KT}\right)}(I_{sc}+I_o)$$

Maximum power output of the solar cell can be evaluated from the following equation [10],

$$P_m = \frac{\left(\frac{eV_m}{KT}\right)^2}{\left(1+\frac{eV_m}{KT}\right)}(I_{sc}+I_o)$$

Maximum cell efficiency of the solar PV panel can be calculated using the following[7],

$$\eta_{max} = \frac{I_m x V_m}{I_T x A_c}$$

C. *Refractive Index Calculation For Arc:*

Refractive index of an Antireflective coating material

$$n_1 = \sqrt{n_0 x n_2}$$

Where,
n1 = refractive index of ARC material
n0 = refractive index of surrounding material. (Glass)
n2 = refractive index of semiconductor material. (Si)
n0 = 1.5 for glass
n2 = 3.44 for silicon

D. *Finding The Optimum Thickness Of An Anti-Reflective Material To Be Coated:*

Thickness of the ARC material can be determined as follows,

$$d_1 = \frac{\lambda}{4n_1}$$

Transmissivity calculation without ARC material can be calculated from the following expression,

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$\theta_2 = \sin^{-1}\frac{\sin\theta_1}{\left(\frac{n_2}{n_1}\right)}$$

Reflectivity when no anti reflection coating,

$$\rho_i = \frac{\sin^2(\theta_2-\theta_1)}{\sin^2(\theta_2+\theta_1)}$$

$$\rho_{ii} = \frac{\tan^2(\theta_2-\theta_1)}{\tan^2(\theta_2+\theta_1)}$$

$$\rho = \frac{1}{2}(\rho_i + \rho_{ii})$$

Transmissivity between air - glass medium and glass – Si wafer can be evaluated from the following,

$$\tau_{r1} = \frac{1-\rho_i}{1+(2M-1)\rho_i}$$

$$\tau_{r2} = \frac{1-\rho_{ii}}{1+(2M-1)\rho_{ii}}$$

$$\tau_r = \frac{1}{2}(\tau_{r1}+\tau_{r2})$$

Total transmissivity

$$\tau = (\tau_r x \tau_a)$$

III. RESULTS AND DISCUSSION

The refractive index of the anti-reflective material should have the refractive index of 2.273 for optimum transmission of light into the silicon substrate. For the calculated value of refractive index, an effictive anti-reflection coating has been identified. The transmissivity and reflectivity of the air to glass are 0.7519 and 0.0417respectively.

The transmissivity and reflectivity of glass to silicon wafer are 0.5137 and0.1563 respectively.The calculated 75.12% of solar radiation is penetrated through the air and glass medium. When this radiation falls on to the absorber (Si) wafer it gets partially reflected and partially absorbed. Only 51.37% of solar radiation penetrates the solar cell obtained from the calculation. Now by introducing the antireflective coating, the transmissivity and reflectivity of MgO to silicon wafer are 0.5956 and 0.1104. This anti-reflective coating increasing the penetration of the solar radiation in the solar cell from 51.37% to 59.56%. So electrical efficiency of the solar cell must be increased by the certain percentage.

Electrical efficiency of the silicon solar cell without anti – reflective coating 6.81% at 32˚c is calculated. Based on the optimum value of the refractive index of the anti-reflective coating material calculated, combination of anti reflection coating material (MgO - ZnO) is selected.

IV. CONCLUSION

Based on the theoretical calculations arrived, the optimum refractive index is 2.273, transmissivity is 0.5137, reflectivity is 0.1563 and efficiency is 6.81% for the silicon solar PV panel without anti-reflective coating.The optimum value of the refractive index of the anti-reflective material 2.273 is used to enhance the electrical efficiency. Based on the optimum value of the refractive index of the anti-reflective material found, combination of ARC material (MgO - ZnO) is selected. By introducing the anti-reflective coating the tranmissivity in the Si wafer gets increased and reflectivity decreased. So the electrical efficiency of the solar cell must be increased by some percentage.

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