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TCAD design of silicon solar cells in comparison of antireflection coatings and back surface field

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ABSTRACT

This paper presents the development of a physically based solar cell simulation using the Silvaco-TCAD simulator. Simulations were performed on a Si based solar cell with antireflection coating (ARC), without ARC and ARC with back surface field. Single layer SiO_2 ARC was used and its effect on each solar cell was analysed. The effect of BSF and AR coatings on the performance of the solar cells were performed using AM 1.5 G. The Si solar cell with SiO_2 AR coating and BSF cell demonstrated increased efficiencies of about 154%, and 77%, respectively, compared with the non-ARC BSF Si solar cell. The addition of the BSF initiated 43% improvement in the efficiency of Si solar cells, compared with 5.9% of the SiO_2 (AR) coated non-BSF Si solar cell. The designed model indicate the potential of combining the SiO_2 AR coating with BSF in the improved fabrication of high-efficiency, low-cost Si solar cells.

1. Introduction

Solar cell simulations helps in understanding and optimising the complicated physical mechanisms involved in photovoltaic devices (PV) [1]. This feature enables a faster creation and higher properties of solar cell. This study will employ the Silvaco-TCAD simulator for modelling solar cells. The use of Silvaco-TCAD simulation has become an essential simulator in the design and analysis of the electrical and optical properties of solar cells [2]. Less absorbing surface of bare silicon can produce lower values of photogeneration rate and thus reduce the overall efficiency of silicon solar cell. This drawback can be minimized by using an anti-reflecting coating (ARC) [3]. On the other hand recombinations also play a vital role in reducing the solar cell efficiencies. A back surface field is capable of reducing recombination velocity (S_b) by converting it into an effective recombination velocity (S_{eff}) at the BSF junction edge [4]. Among of the factors that help to improve solar cell efficiency is type of material, design of the surface structure used, doping concentration, light absorption at surface area and subsurface [5,6].

Silvaco TCAD simulator used in this study consists of two main parts which are ATHENA and ATLAS [7]. ATHENA contributes in the designing of the solar cell structure while ATLAS is responsible to produce the result such as the efficiency of the solar cell. Device simulators ATHENA and ATLAS were developed by Silvaco International and are used as a tool in modeling solar cell [8]. ATLAS has its best use with other collective tools such as DECKBUILD and TONYPLOT. It can provide insight into the internal physical mechanisms associated with device operation and to estimate the electrical behaviour of

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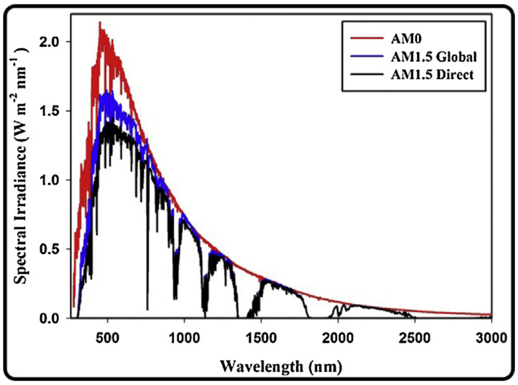

Fig. 1. AM0 (red), AM1.5G (blue), and AM1.5D (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

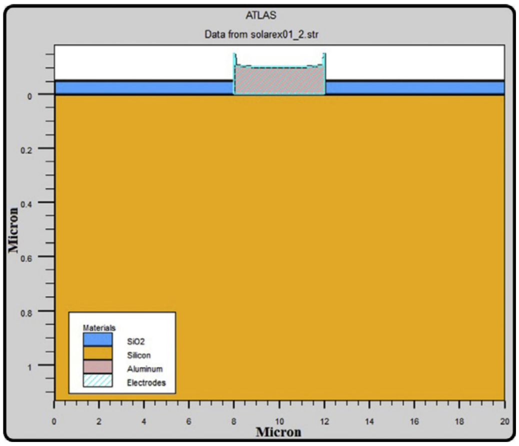

Fig. 2. Solar cell structure with ARC.

specified semiconductor structures. On the basis of virtual fabrication structure of a solar cell, ATLAS can extract the electrical characteristics [9]. On the completion of simulation, a wide variety of outputs as well as photogeneration rate, spectral response, current-voltage and quantum efficiencies are available to the solar cell device designer.

The aim of this study is to investigate the antireflection coating (ARC) and back surface field effects on the efficiency and the spectral response of silicon solar cells. Furthermore, it analyze the combination of ARC with a BSF cell in order to enhance the efficiency of a single *p-n* junction Si based solar cell.

2. Methodology

Although any kind of solar spectrum and photon concentration can be used, for the present study, a standard AM1.5G as shown in Fig. 1, is used as a light source to illuminate the designed cell devices developed using the Silvaco-TCAD. To simulate the solar cell, *p-n* junction was built on the substrate using the proper doping concentrations. The p-type region of solar cell was designed with Boron impurities of $10^{16}/cm^3$, while the n-type region was created by using phosphorous impurities to be doped into the silicon layer with doping concentration of $2 \times 10^{19}/cm^3$. Following this step the ARC single layer was created using the silicon dioxide (SiO_2) material [10]. ARC layer on the solar cell must be able to absorb the maximum light with minimum reflectance thus improving the efficiency of the solar cell. After the ARC layer, back surface field (BSF), was then added in the solar cell design. The final step is to create the back and front contacts where Aluminum was used as a contact material in the designing of the solar cell structure [11]. After designing the standard solar cell, two other types of solar cells were also created using Silvaco-TCAD simulator.

3. Results and discussion

These entire figures of the 2D solar cell models are very illustrative generating snapshots of the structure, and how different parameters are dispersed throughout its area provides a valuable insight. Fig. 2 represents the solar cell structure with ARC while solar cell without ARC is shown in Fig. 3. The TONYPLOT has shown different contours of the recombination