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Nanocrystalline Silicon (nc-Si:H) and Amorphous Silicon (a-Si:H) Based Thin-Film Multijunction Solar Cell

(Silikon Nanohablur (nc-Si: H) dan Silikon Amorfus (a-Si: H) Berasaskan Sel Nipis Filem Multisimpangan Suria)

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ABSTRACT

A novel thin-film multijunction solar cell based on nanocrystalline silicon (nc-Si:H) is presented in this paper. Existing thin-film double junction solar cells are based on amorphous silicon carbide (aSiC:H) and amorphous silicon layers. Such solar cells have limited efficiency due to lower absorption and poor charge transport properties of the a-SiC:H layer. These solar cells have maximum achieved efficiency of about 8.8%. In this work, a-SiC:H has been replaced with nc-Si:H layer and the double junction solar cell has been redesigned. The proposed structure has been simulated with Silvaco TCAD (ATLAS). The simulated results indicated a step increase in the performance of the solar cell with open circuit voltage V_{oc}=2.096 V and efficiency η = 10.2%. It was proven that the nc-Si:H is a suitable material for the development of an efficient thin film multijunction solar cell.

Keywords: Multijunction; nanocrystalline silicon; solar cell; TCAD; thin-film

ABSTRAK

Sebuah filem nipis sel suria multisimpangan berdasarkan silikon nanohablur (nc-Si:H) dibincangkan dalam kertas ini. Filem nipis dua-simpangan sel suria yang sedia ada adalah berdasarkan silikon karbida amorfus (aSiC:H) dan lapisan silikon amorfus. Sel suria seperti ini mempunyai kecekapan terhad kerana penyerapan yang lebih rendah dan sifat a-SiC: lapisan H yang mempunyai pengangkutan caj yang lemah. Sel suria ini mempunyai kecekapan maksimum kira-kira 8.8%. Dalam kajian ini satu lapisan SiC:H telah digantikan dengan lapisan nc-Si:H dan simpang sel suria kembar telah direka semula. Struktur yang dicadangkan itu telah disimulasikan dengan Silvaco TCAD (ATLAS). Keputusan simulasi menunjukkan peningkatan ketara dalam kecekapan sel suria dengan voltan litar terbuka VLT = 2.096 V dan kecekapan η = 10.2%. Ia membuktikan bahawa nc-Si:H adalah bahan yang sesuai untuk perkembangan filem multisimpangan nipis sel suria yang cekap.

Kata kunci: Filem nipis; multisimpangan; sel suria; silikon nanohablur; TCAD

INTRODUCTION

The applications of thin film solar cells have paved way for acceptable efficient and cost effective photovoltaic devices. Thin-film solar cells use lesser amount of material with cheaper substrates such as glass or plastic foil that leads to reduced cost of the materials and fabrication. The efficiency of solar cell can be effectively enhanced by an application of different band gap materials. This leads to the improved utilization of sunlight spectrum. An efficiency of 8.82% has been attained by the thin film double junction cell employing aSiC:H/a-Si:H configuration (Yunaz et al. 2010). Optimizing multijunction structure is of vital importance in enhancing the efficiency of solar cell.

Wide band gap hydrogenated nanocrystalline silicon (nc-Si:H) is relatively a new material that has attracted attention recently (Li et al. 2010). It has advantages such as higher electrical conductivity (Filonovich et al. 2009), higher mobility (Lee et al. 2005) and better stability as compared to the amorphous materials (Filonovich et al. 2008). In this work, nc-Si:H subcell is formed in tandem with a-Si:H to form multijunction solar cell. With wide band gap top cell, high open circuit voltage can be achieved; consequently leading to higher conversion efficiency.

The standard value of AM 1.5 100 mW/cm^2 was used for measuring the I-V characteristic of the proposed structure. These results indicated that nc-Si:H is beneficial to use as an absorber layer in thin film structure and it will open a new era of developing highly efficient and cheaper thin film solar cells.

TCAD MODEL DESCRIPTION

An industrial simulator Silvaco TCAD was used in this work for the analysis and simulation of the proposed nc-Si:H/a-Si:H structure. In order to simplify calculations, flat substrate was used instead of textured substrate. Moreover, ZnO back reflector was also employed in the structure. This section described structural and electrical parameters used for the device simulation.

Device Structure The device configuration of the investigated nc-Si:H/a-Si:H cell is publicized schematically in Figure 1. A 60 nm thick layer of indium doped tin oxide (ITO) was inserted at the top of the device. Indium doped tin oxide (ITO) has characteristics such as higher transparency for minimizing optical losses and high conductivity for minimizing resistive losses. For contact layers at the top and back of the device, aluminum material was used. The solar cell layer configuration used in this work is in the following sequence: (from top to bottom) ITO (60 nm)/p-nc-Si:H (15 nm)/i-buffer-nc-Si:H (8 nm)/i-nc-Si:H (t_{top})/n-a-Si:H (20 nm)/ZnO interlayer (50 nm)/ p-a-Si:H (15 nm)/i-buffer-a-Si:H (8 nm)/i-a-Si:H (t_{bot})/n-a-Si:H (20 nm)/ZnO (100 nm)/Al. The parameter for optimization is the absorber layer thickness't' nm. This parameter is to be optimized during simulation for better device performance. At the p/i interface, a wide band-gap buffer layer was introduced which assists in preventing the back-diffusion of carriers thus reducing carrier recombination at the interface (Suntharalingam et al. 1994).

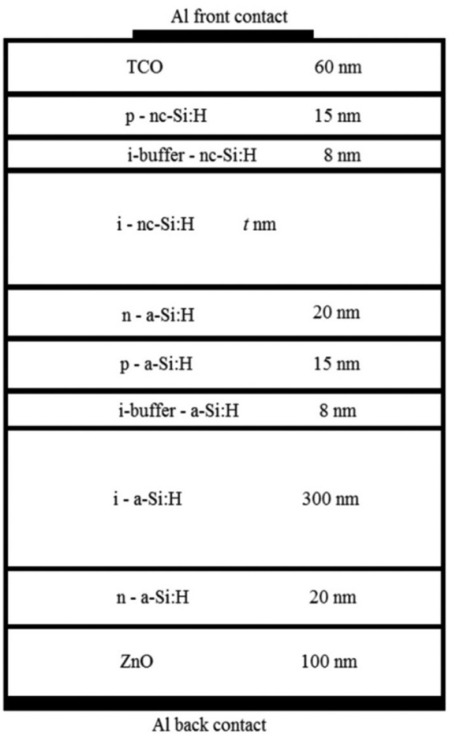


FIGURE 1. Thin-film double junction (nc-Si:H/a-Si:H) structure

Electrical Parameters The characterization behavior of solar cells can be accurately modeled by incorporating the parameters shown in Table 1. The intrinsic absorber layer used for our multijunction configuration was lightly doped (about 1×10^{12} cm^{-3}). The electrical parameters for different materials are tabulated in Table 1. The relative permittivity value of 11.9 was used for each layer.

RESULTS AND DISCUSSION

The simulated results were viewed with the help of TONYPLOT command in Silvaco TCAD. Efficiency (η) of the device structure was analyzed by changing the intrinsic layer thickness of the top cell nc-Si:H. Figure 2 shows the energy band diagram at open-circuit voltage.

Wide band gap nc-Si:H can be obtained by decreasing the size of Si crystallites to a nanometer range. Delley and Steigmeier (1993) have predicted that the Si clusters band gap increase with L^{-1} , where L is the cluster diameter. In nc-Si:H, the size of Si crystallites was sufficiently small resulting in a wider band gap material.

The efficiency (η) versus top cell intrinsic layer thickness graph is presented in Figure 3(a). During the course of simulation, the a-Si:H absorber thickness was fixed at 300 nm. It was analyzed that by increasing the absorber thickness, the efficiency tends to increase up till 650 nm. This is because of the availability of large volume for creating electron-hole pairs. It then decreases gradually afterwards because thicker layer will introduce more defect traps and recombination centers. The I-V curve is shown in Figure 3(b).

CONCLUSION

A double junction solar cell structure based on nc-Si:H/a-Si:H was implemented using Silvaco TCAD. Characterization parameters like energy band diagram, efficiency and I-V curve were demonstrated. By taking into consideration the top absorber thickness, the solar cell output performance was studied and analyzed.

TABLE 1. Electrical parameters used for double junction solar cell structure

Parameters	*P*-layer (nc-Si:H/a-Si:H)	*i* -buffer layer (nc-Si:H/a-Si:H)	*i*- layer (nc-Si:H/a-Si:H)	*N* -layer (a-Si:H)
Electron affinity χ (eV)	4.05/4.05	4.05/4.05	4.05/4.05	4.05
Band gap E_g (eV)	2.05/1.80	2.07/1.82	2.00/1.72	1.72
Electron mobility μ_n (cm^2/V-s)	100/10	100/10	100/10	10
Hole mobility μ_p (cm^2/V-s)	20/2	20/2	20/2	2
Effective DOS in conduction band N_c (cm^{-3})	$3\times10^{19}/2.5\times10^{20}$	$3\times10^{19}/2.5\times10^{20}$	$3\times10^{19}/2.5\times10^{20}$	2.5×10^{20}
Effective DOS in valence band N_v (cm^{-3})	$2\times10^{19}/2.5\times10^{20}$	$2\times10^{19}/2.5\times10^{20}$	$2\times10^{19}/2.5\times10^{20}$	2.5×10^{20}

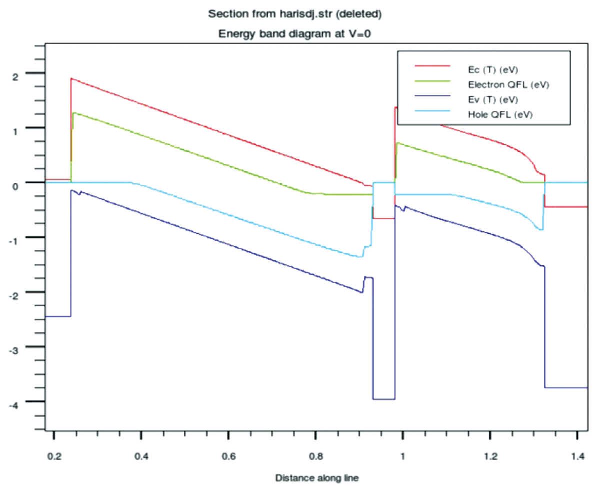
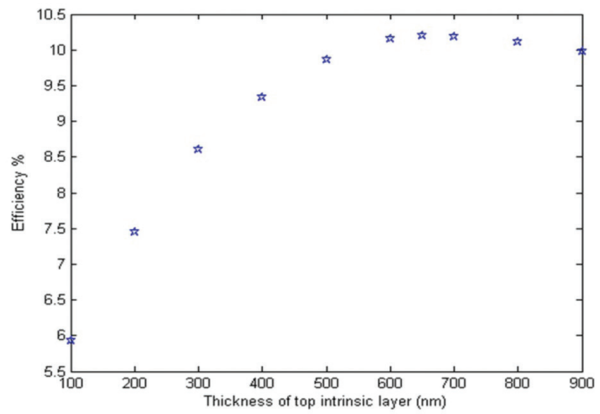
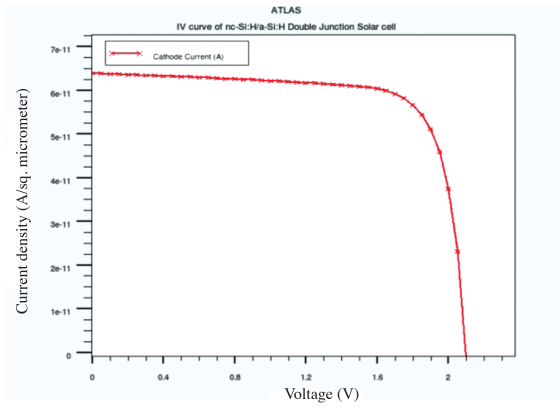


FIGURE 2. Energy Band diagram of double junction solar cell



(a)



(b)

FIGURE 3. Output performance and characterization of double junction (nc-Si:H/a-Si:H) structure at varying top cell intrinsic layer thickness; (a) Efficiency (η) in % vs. intrinsic layer thickness. Maximum efficiency of 10.2% at 650 nm and (b) I-V curve of DJ solar cell with J_{sc}=6.393 mA/cm^2 and V_{oc}=2.096 V measured at 650 nm top absorber thickness

TCAD simulation results showed that the best conversion efficiency of 10.2% (J_{sc}= 6.393 mA/cm^2, V_{oc}= 2.096 V and FF = 0.761224) using optimized top intrinsic layer (nc-Si:H) thickness of 650 nm and bottom intrinsic layer (a-Si:H) thickness at 300 nm. Because of its better electrical properties, nc-Si:H cell holds brighter prospects for its use in thin-film solar cells.

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