Optik 153 (2018) 43–49

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Optimizing the optical performance of ZnO/Si-based solar cell using metallic nanoparticles and interface texturization

H. Ferhati[a], F. Djeffal[a,b,*], K. Kacha[a]

[a] LEA, Department of Electronics, University of Batna 2, Batna 05000, Algeria
[b] LEPCM, University of Batna 1, Batna 05000, Algeria

ARTICLE INFO

Article history:
Received 19 June 2017
Accepted 29 September 2017

Keywords:
Nanoparticles
Grooves
Absorption
Light trapping
Optimization
PSO

ABSTRACT

In this paper, we propose a new n-ZnO/p-Si hetero-junction solar cell design based on both interface engineering and metallic nanoparticles aspects. The merits of using both metallic nanoparticles and grooves morphology in the ZnO/p-Si interface to improve solar cell optical performance are investigated numerically using accurate solutions of Maxwell's equations. It is found that the proposed structure suggests the possibility to achieve the dual role of improved light-scattering in the Si absorber layer as well as enhancing the absorption in the ZnO thin-film through the Surface Plasmon Resonance effect. Besides, the proposed design exhibits superior optical performance and offers improved total absorbance efficiency (TAE) as compared to the conventional counterpart. Moreover, particle swarm optimization (*PSO*)-based approach is exploited for the geometrical optimization of the proposed design to achieve higher light trapping capability. It is found that the optimized design yields 50% of relative improvement in the ZnO/p-Si-based solar cell TAE which confirms excellent capability of the proposed design approach for modulating the electric field behavior inside the solar cell structure. The obtained results indicate that the optimized n-ZnO/p-Si hetero-junction solar cell offer the potential for high conversion efficiency at low costs which make it valuable for photovoltaic application.

1. Introduction

The sunlight has the prospective to power the Earth's total energy requirements. However, photovoltaic panels still constitutes an extremely small portion of our power production owing to its high cost as compared to traditional energy sources [1]. Crystalline Silicon-based solar cells have enabled a huge growth in the solar cell conversion efficiency, which imposes a corresponding increase in solar cell fabrication cost [2–6]. In this context, the continuous requirement of high cost/efficiency ratio for achieving distinctive photovoltaic performance implies deficiencies mainly related to the discovery of low-cost materials that provide earth-abundant solar absorption. However, thin-film solar cells based on hydrogenated amorphous silicon present a viable alternative material due to their low-cost and acceptable conversion efficiency. Although, plasma-enhanced deposition is in fact needed for the perfect growing of the amorphous silicon that unfortunately can complicate the fabrication process [5–8]. In this light, holistic design of low cost solar cell structures with an in-depth understanding of the material optical proprieties brings the photovoltaic performance to unprecedented levels. For this purpose, the use of bilayer based on wide band gap materials such as ZnO and aluminum doped ZnO (AZO) with higher conductivity developed on the

* Corresponding author at: LEA, Department of Electronics, University of Batna 2, Batna, 05000, Algeria.
E-mail addresses: faycal.djeffal@univ-batna2.dz, faycaldzdz@hotmail.com, faycaldzdz@hotmail.com (F. Djeffal).

https://doi.org/10.1016/j.ijleo.2017.09.127
0030-4026/

p-Si absorber layer could improve the efficiency/cost ratio [9,10]. Basically, the direct deposition at low temperatures of the ZnO layer on the c-Si absorber layer constitutes the major benefit of this alternative structure [9–12]. This advantage enables lower fabrication cost compared to both c-Si and thin film solar cell technologies. Besides, the ZnO/AZO bilayer provides the opportunity for double functionalities, where it behaves as a TCO, and solar cell emitter with perfect Ohmic contact. Despite the cost effectiveness of the n-ZnO/p-Si based solar cell, the low absorbance efficiency represents the most important issue that should be addressed for achieving superior photovoltaic performance. In this perspective, several recent works have concentrated on enhancing the n-ZnO/p-Si based solar cell conversion efficiency through originating innovative designs [11–14]. However, the incapability to highly improve the solar cell absorption behavior especially in both visible and near-infrared regions still persist which leads to reduced its electrical efficiency. In this regard, it is of great importance to develop new design methodologies for recording the desired enhancement regarding the solar cell optical performance. To the best of our knowledge, no investigations have been carried out for improving the n-ZnO/p-Si optical performance by introducing both interface engineering and Ag metallic nanoparticles paradigms. In this framework, we propose in this paper a new approach based on n-ZnO/p-Si interface engineering and metallic nanoparticles to improve the light trapping capability. The merits of using both Ag nanoparticles and engineered ZnO/p-Si interface to enhance the photovoltaic performance are analyzed numerically using accurate solutions of Maxwell's equations. It is found that the proposed structure suggests the possibility to achieve the dual role of improved light-scattering in the Si absorber layer as well as enhancing the absorption in the ZnO thin-film through the SPRE. Moreover, particle swarm optimization (*PSO*)-based approach is exploited for an eventual geometrical optimization of the proposed design to achieve highest possible optical performance. The obtained results indicate that the optimized n-ZnO/p-Si hetero-junction solar cell offers the potential for high conversion efficiency at low costs which make it valuable for photovoltaic application.

2. Numerical modeling

Principally, the key idea behind the n-ZnO/p-Si based solar cell resides mainly on using bilayer based on low cost materials with wide band gap such as ZnO and aluminum doped ZnO (AZO) developed on the p-Si absorber layer. In the proposed design, versatile design amendments are adopted in order to improve the n-ZnO/p-Si based solar cell optical behavior. Firstly, the design alteration is made in ZnO/p-Si interface level by assuming textured c-Si with grooves morphology, where w and h are the grooves width and height, respectively. Secondly, we suggest introducing Ag metallic nanoparticles inside the ZnO layer with the aim of enhancing the solar cell optical performance. In this context, Fig. 1 illustrates schemas of both conventional n-ZnO/p-Si based solar cell and the proposed design including both interface engineering metallic nanoparticles aspects. For our numerical modeling t_{si} is the p-Si region thickness, t_z denotes the ZnO material thickness R and P are the nanoparticles radius and position, respectively, and t_a represents the AZO top layer thickness.

The proposed design amendments of the n-ZnO/p-Si based solar cell impose many mathematical difficulties for an eventual analytical modeling, which are associated with the structural complexity that can obscure the analytical solution of the absorbance equations. Moreover, for the accurate modeling of the proposed design, we cannot ignore both diffraction and plasmonic effects which lead to some modeling bottlenecks mainly related to the accurate resolution of Maxwell's equations. In this framework, numerical techniques can deal with the aforementioned critical problems and provide the possibility for modeling efficiently the proposed structure optical behavior. For this purpose, the discretization of Maxwell's equations using the FDTD method provided by the ATLAS-2D device simulator using 2-D LUMINOUS module, [15], can be efficient for perfectly model the investigated solar cell optical behavior incorporating the impact of both interface texturization and Ag

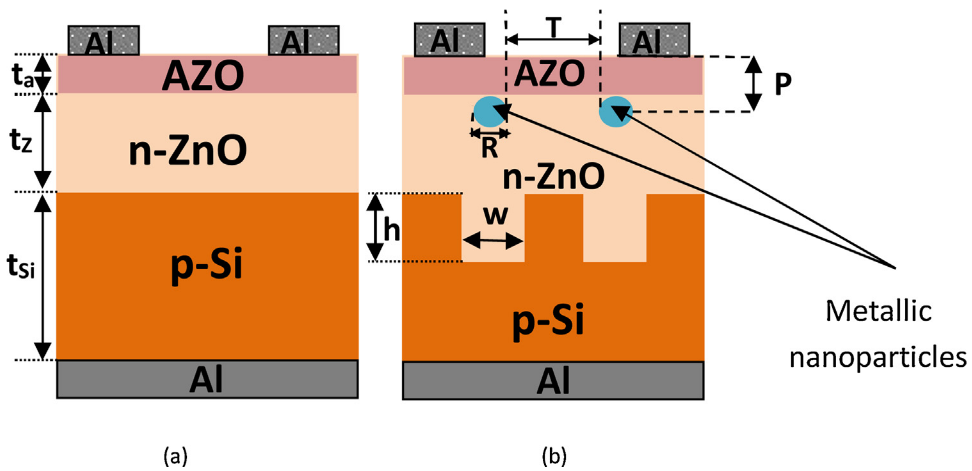

Fig. 1. Cross-sectional view of both n-ZnO/p-Si based hetero-junction solar cell and the proposed design including interface texturization and Ag nano particles.