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Comprehensive design and analysis of thin film Sb_2S_3/CIGS tandem solar cell: TCAD simulation approach

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Abstract

This research presents a design and analysis of a tandem solar cell, combining thin film wide bandgap Sb_2S_3 (1.72 eV) and narrow bandgap CIGS (1.15 eV) for the top and bottom sub-cells, respectively. The integration of all thin film layers enhances flexibility, rendering the tandem solar cell suitable for applications such as wearable electronics. To optimize the power conversion efficiency (PCE) of the tandem solar device, advanced technology computer-aided design (TCAD) simulation tools are employed to estimate loss mechanisms and fine-tune parameters for each layer. An experimentally validated optoelectronic model is introduced, calibrated and validated against fabricated reference solar cells for the individual top and bottom cells. The calibrated model is then utilized to propose optimization routines for the Sb_2S_3/CIGS tandem solar cell. The initial tandem cell exhibits a J_{SC} of 15.72 mA cm^{-2} and a PCE of 15.36%. The efficiency drop in the tandem configuration is identified primarily in the top cell. A systematic optimization process for the top cell is initiated, exploring various configurations, including HTL-free and ETL-free setups. Moreover, an np homojunction structure for the top cell is proposed. Optimization routines are applied that involve determining optimal thickness and doping concentration of the *n*-layer, investigating the effect of *p*-layer doping concentration, and exploring the influence of the work function of the front contact. As a result, the tandem cell efficiency is significantly improved to 23.33% at the current matching point (CMP), with a J_{SC} of 17.15 mA cm^{-2}. The findings contribute to the advancement of thin-film tandem solar cell technology, showcasing its potential for efficient and flexible photovoltaic applications.

1. Introduction

Nowadays, energy demand is escalating rapidly, with clean energy sources, particularly solar cells, representing favorable outcomes. Solar energy stands out as a highly effective substitute for green energy resources [1]. Silicon-based solar cells, constituting 90% of the solar cell industry [2, 3], dominate the photovoltaic (PV) market. The efficiency of crystalline silicon solar cells has surpassed 25% [4]. Both simulation and experimental endeavors have been addressed to lower the cost of different Si-based PV cells; yet lower efficiencies resulted [5–11]. The Shockley and Queisser model established a maximum power conversion efficiency (PCE) of 33.7% for a single junction cell having an absorber bandgap of about 1.34 eV [12]. However, these cells have limitations in photon absorption since they can only absorb photons equal to or greater than the material's energy gap. Tandem (multi-junction) PV systems, on the other hand, have emerged as a solution, overcoming these